Stock Assessment of Chinook Salmon in the Naknek River, 2003–2004

by

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and

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Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	$(F, t, \chi^2, \text{etc.})$
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	E
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

The abundance of Chinook salmon (*Oncorhynchus tshawytscha*) that returned to spawn in the mainstem of the Naknek River and Big Creek in 2003 and 2004 was estimated with radiotelemetry and a mark–recapture experiment. Age, sex, and length compositions were also estimated. Drift gillnets were used near Horseshoe Bend of the lower Naknek River to capture and tag Chinook salmon with a combination of radio transmitters and external tags during June and July of each year. Two recapture events were conducted; 1 at a U. S. Fish and Wildlife Service weir on Big Creek and 1 with drift gillnets at mainstem Naknek River spawning areas. Abundance was estimated in 2003 for fish over 640 mm from mid eye to tail fork (METF) as 4,592 (SE = 1,372) Chinook salmon in Big Creek and 15,996 (SE = 5,994) Chinook salmon in the mainstem of the Naknek River. Abundance was estimated in 2004 for fish over 640 mm METF as 11,282 (SE = 1,513) Chinook salmon in Big Creek and 24,742 (SE = 8,087) Chinook salmon in the mainstem of the Naknek River. In 2003, most males and females in the Big Creek escapement were age 1.1 and 1.4, respectively, and most males and females in the mainstem escapement were age 1.3. In 2004, most males and females in the Big Creek escapement were age 1.3 and most males and females in the mainstem escapement were age 1.2 and 1.4, respectively.

Key words: Chinook salmon, Naknek River, Big Creek, mark–recapture, escapement, abundance, telemetry, radio tag, length, age and sex composition.

INTRODUCTION

The Naknek River (Figure 1) supports one of the largest Chinook salmon (*Oncorhynchus tshawytscha*) sport fisheries in Southwest Alaska. Sport fishing effort for all sport fish species in the Naknek River drainage has increased from 4,675 angler-days in 1977 to a 5-year average (1998–2002) of 17,823 angler-days, which equates to about 18% of the total effort in Southwest Alaska (Mills 1979-1980, 1981a-b, 1982-1994; Howe et al. 1995-1996, 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006a). Harvest of Chinook salmon in the sport fishery peaked in 1987 (9,069 fish) but regulatory restrictions have reduced the 5-year (1998–2002) average harvest to approximately 2,614 fish (Dye and Schwanke, unpublished[1]). Naknek River Chinook salmon are also harvested in commercial and subsistence fisheries. While sport harvests have declined since 1988, exploitation rates of Naknek River Chinook salmon have exceeded 50%, and in 1989 the total exploitation rate based on aerial escapement surveys approached 80%. Therefore, there was a clearly defined need to obtain more refined stock assessment information.

The desired escapement index for the Naknek River drainage is a sustainable escapement goal (SEG) of 5,000 spawning Chinook salmon as estimated by aerial surveys (Fair et al. 2004). Sport harvests are measured through the Alaska Department of Fish and Game (ADF&G), Division of Sport Fish, Statewide Harvest Survey (SWHS) and creel surveys. Commercial harvest is reported to ADF&G on fish tickets and has a 5-year (1998–2002) average of 911 Chinook salmon (Westing et al. 2005). Subsistence harvest is estimated from returns of subsistence permits and has a 5-year (1998–2002) average of 939 Chinook salmon (Westing et al. 2005).

The Division of Sport Fish has implemented closures, harvest and gear restrictions, and emergency order restrictions to conserve Chinook salmon in the Naknek River drainage. In 1987, a season (1 May to 31 July) was established for Chinook salmon and new regulations reduced bag and possession limits to 3 per day, 1 of which may be over 28 inches in length and limited

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[1]   Dye, J. E. and C. J. Schwanke. Area management report for the recreational fisheries of the Southwest Alaska sport fish management area, 2003. Alaska Department of Fish and Game, Anchorage, unpublished manuscript.

sport fishing gear to only artificial lures due to concern over increasing sport harvest (Dunaway and Sonnichsen 2001). Emergency orders closed the outlets and lower reaches of King Salmon and Pauls creeks during the early 1990s to protect Chinook salmon during spawning (Dunaway and Sonnichsen 2001). This action was in response to 4 consecutive years of below average escapements in these drainages. The closure of the confluence of King Salmon Creek and the Naknek River became regulation in 1995. In 1997, angling closures in Pauls and King Salmon creeks were clarified by the Alaska Board of Fisheries and an annual limit of 5 Chinook salmon was adopted for this fishery (Dunaway and Sonnichsen 2001).

Estimates of Chinook salmon escapement are made using an index of aerial survey counts for which accuracy is unknown. The 2000 aerial survey assessment of the Chinook salmon stock indicated that desired escapement was not met; however, escapements were met for 2001 through 2004 (Westing et al. 2005).

To address the need for more refined stock information, this project estimated the abundance, composition, and spawning distribution of Chinook salmon in the Naknek River drainage for 2003 and 2004 with the use of radiotelemetry, Floy[2] tags, a weir on Big Creek, and a recapture event using gillnets conducted near the mainstem spawning grounds. Accurate assessment of abundance of Chinook salmon in the Naknek River allowed for a comparison of estimated abundance to aerial survey indices in addition to a comparison of removals by the sport, inriver commercial, and subsistence fisheries. These comparisons will assist fishery managers in determining the quality of prior escapement information and the status of this stock relative to removals by all inriver user groups.

The 2003 and 2004 studies had 2 objectives: 1) estimate the abundance of Chinook salmon in the Naknek River for all waters upstream of Horseshoe Bend excluding King Salmon Creek and Pauls Creek; and 2) estimate age, sex, and length compositions of Chinook salmon in the Naknek River upstream of Horseshoe Bend excluding King Salmon Creek and Pauls Creek.

STUDY AREA

The Naknek River drainage is located in Southwest Alaska. A significant portion of the drainage is composed of Naknek Lake and the outlet drainage of the Naknek River (Figure 1). The Naknek River flows past the community of King Salmon into Bristol Bay near the community of Naknek. The drainage supports spawning populations of all 5 species of Pacific salmon. Most Chinook salmon spawning in the Naknek River drainage occurs within the Naknek River and its tributaries. Very little spawning occurs in the remainder of the drainage, which is composed of several tributaries and large lakes, most notably Naknek Lake. Significant spawning areas of the Naknek River include the upper mainstem of the Naknek River, Big Creek, King Salmon Creek, and Pauls Creek. Aerial escapement surveys are conducted for these spawning locations.

METHODS

The number of Chinook salmon that spawn in the mainstem of the Naknek River (mainstem spawners) and Big Creek (Big Creek spawners) was estimated from a 2-event mark–recapture experiment for a closed population (Seber 1982). Chinook salmon were captured daily with drift

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[2]   Product names used in this publication are included for completeness but do not constitute product endorsement.

gillnets on the lower Naknek River between Horseshoe Bend and Pauls Creek for the "marking event" (Figure 2). Radio tags and Floy tags were used as the "mark." Sampling was conducted over most of the run from 1 June to 31 July in 2003, and from 15 June to 31 July in 2004. An effort was made each day to capture salmon in proportion to actual run strength and size composition passing the capture location. Distribution and movement of radiotagged salmon to spawning areas was determined using a combination of aerial and boat telemetry surveys, and 5 stationary tracking stations. Due to differences in run timing between Big Creek and mainstem spawners, 2 different recapture "events" were conducted to estimate the number of fish that spawn in both Big Creek and the mainstem of the Naknek River. Marked fish were detected (via video or live trap) at a weir on Big Creek operated by the U. S. Fish and Wildlife Service (USFWS). A second recapture location was designated on the mainstem of the Naknek River between Rainbow Bend and Shawbeck's cabin (Figure 2). Chinook salmon were captured with gillnets at this second location. Age, sex, and size information were collected from all captured Chinook salmon to aid in testing of assumptions of equal probability of capture.

MARKING EVENT

In 2003, two crews of 2 technicians in outboard-powered skiffs drifted gillnets to capture and tag Chinook salmon in the lower Naknek River between Horseshoe Bend and Pauls Creek (Figure 2). This marking event was conducted from 1 June through 31 July. Only 1 crew sampled each day, based on a 4-day work week schedule. There was 1 day of overlap when each crew worked on the same day; 1 crew sampled with gillnets, while the other crew tracked radiotagged fish, downloaded data from fixed tracking stations, and mended nets. In 2004, two crews sampled with gillnets each day from 21 June to 7 July. During the remainder of the season, 1 crew sampled each day as in 2003. Increased effort between 21 June and 7 July was in response to the observation that a disproportionately high number of tagged fish entered Pauls and King Salmon creeks during this time period in 2003. Due to similar run timing of tributary spawning fish, tagged fish movement into Pauls and King Salmon creeks resulted in a lower marked to unmarked ratio of fish at the Big Creek weir than in the mainstem of the Naknek River in 2003. Increased effort during this time frame in 2004 resulted in more tagged fish destined for Big Creek, with the intent of realizing similar marked to unmarked ratios at the 2 recapture sites.

Fish were captured by drifting 18 m–long multi-fiber nylon gillnets with mesh sizes of 5.5 in (14.0 mm) and 7.5 in (19.1 mm) (stretched measurement) and a depth of approximately 30 ft (9 m). These 2 mesh sizes are hereafter referred to as 5.5-in mesh and 7.5-in mesh. The use of 2 mesh sizes allowed the capture of a representative sample of Chinook salmon greater than 450 mm (length from mid eye to tail fork, METF). Attempts were made to capture Chinook salmon and distribute radio tags over the span of the run and in proportion to run strength, size composition, and bank of migration. Sampling occurred with approximately equal effort on the left bank (north bank), right bank (south bank) and in midchannel to avoid selection for bank-orientated stocks. Based on catch per unit effort (CPUE) information from sampling during 2002 at various tide stages, netting occurred for 7 hours each day from 4.5 hours prior to daylight low slack tide until 2.5 hours after the same slack tide. Information recorded for each drift included date, mesh size, capture location relative to bank, tide stage, soak time, and the number of each species captured. Sampling periods consisted of the use of a single-sized mesh for a 1-hour period with drifts alternated along each bank and the midchannel. Mesh sizes were alternated systematically between sampling periods. Between sampling periods, soak time was expected to

vary inversely with run strength and CPUE as more time would be spent handling and measuring more fish when catch rates were high.

During the tagging effort, captured Chinook salmon were retrieved immediately after entanglement in the net webbing. Chinook salmon were placed in an aerated tote of water and untangled or cut free from the net. All fish captured, regardless of health, were sampled to estimate the age, sex, and length (ASL) composition of the escapement. Three scales were collected from all fish from the left side of the fish approximately 2 rows above the lateral line along a diagonal line downward from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin and placed on gum cards for aging (Welander 1940). Scale impressions were made on acetate cards and viewed at 100× magnification using equipment similar to that described by Ryan and Christie (1976). Ages were determined from scale patterns as described by Mosher (1969).

TAGGING AND TELEMETRY PROCEDURES

This study was designed to implant radio tags into 300 Chinook salmon. Only Chinook salmon greater than 450 mm METF length received radio tags. Radio tags were inserted through the esophagus and into the upper stomach using a 30-cm plastic tube with a diameter equal to that of the radio tags. The radio transmitter was pushed through the esophagus such that the antenna end of the radio tag was seated 0.5 cm posterior to the posterior base of the pectoral fin. Implants were performed without the use of anesthesia.

Radio tags were Model Five pulse encoded transmitters from ATS[3]. The tags were 5.5 cm long, 1.9 cm in diameter, and weighed 24 g in air with a 30-cm external whip antenna. Each radio tag was distinguishable by a unique frequency and encoded pulse pattern. Twelve frequencies spaced approximately 30 kHz apart in the 153 MHz range with 25 encoded pulse patterns per frequency were used for 300 uniquely identifiable tags. Transmitters had a mortality option that changed the pulse rate of the signal if a transmitter did not move for 8 hours. This was used to identify mortalities and expelled transmitters. Prior to tagging fish, all radio tags were tested to assure proper working condition.

Following radio transmitter insertion, inriver migrations of salmon were tracked by 5 fixed tracking stations and by aerial and boat surveys. Fixed tracking stations were located on the mainstem below Horseshoe Bend, the bridges at Pauls and King Salmon creeks, the weir at Big Creek, and below Rainbow Bend of the mainstem (Figure 2). Each station included 2 deep cycle batteries, an ATS Model 5041 Data Collection Computer (DCC II), an ATS Model 4000 receiver, a housing box, and 1 Yagi antenna. The receiver and DCC were programmed to scan through the frequencies at 3 s intervals. When a signal of sufficient strength was encountered, the receiver paused for 5 s, and tag frequency, tag code, signal strength, date, and time were recorded on the data logger. The relatively short cycle period helped minimize the chance that a radiotagged fish would swim past the receiver site without being detected. Recorded data were downloaded to a laptop computer every 7–10 days. Aerial surveys of the mainstem of the Naknek River, Pauls Creek, King Salmon Creek, and Big Creek were conducted bi-weekly from 1 June through 15 August each year. Boat surveys were conducted periodically as needed to

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[3] Advanced Telemetry Systems, Isanti, Minnesota. Use of this company name does not constitute endorsement, but is included for scientific completeness.

locate tags and possibly recover tags indicating mortality. This level of coverage allowed the determination of the number of tagged fish that died or expelled transmitters, exited the survey area downriver, or that spawned in any of the 3 tributaries or the mainstem.

All radiotagged fish received an individually numbered FT-1-94 Floy dart tag and/or Peterson disc tag. The Floy tags were inserted on the left side of the fish between the first and second fin ray of the dorsal fin. This tag location highlighted the colored tag against the darkness of the dorsal fin for easier detection by video of tagged fish at the Big Creek weir. The USFWS used video enumeration to count the majority of fish that passed through the weir. While tags were detectable, tag numbers were not visible from video recordings and as a result, the tag number of each observed fish was unknown. A different color, banding pattern, or tag type was used during each week of the survey. This allowed video observers to determine which week a Chinook salmon passing through the Big Creek weir was tagged, and gave additional insight on the timing of Big Creek spawners entering the Naknek River.

The USFWS operated a weir on Big Creek from June through September in both 2003 and 2004. The following methods were used to monitor Chinook salmon passage at the weir: 1) recording and counting passage with a video camera mounted adjacent to a chute in the weir and 2) directing all passing fish into a live trap box for sampling. Both the total number of Chinook salmon passing the weir and the total number of marked Chinook salmon passing the weir were recorded. When a marked Chinook was observed on video, the time, date, tag coloration, and tag type was recorded. A file containing a photo of each individual tagged fish that was observed from video was saved in computer format. The live trap was used to capture fish in order to satisfy a weekly sampling goal to collect ASL data. Tag number, type, and color of all marked fish sampled from the live trap were recorded.

ESTIMATION OF ABUNDANCE

Assignment of Fate

For the purposes of mark–recapture abundance estimation, every radiotagged fish was assigned 1 of 4 possible fates:

1. a fish that loses its tag
2. a fish that dies as a result of handling
3. a fish that survives tagging and handling and successfully migrates to a spawning area
4. a fish that is never located after being tagged and released or is harvested before migrating to a spawning area

Tagged fish experiencing fate numbers one, two, or four were not considered part of the marked portion of the experiment. Fish having fate number three constituted the marked sample (*M*). Fates of radiotagged fish were determined from fixed stations, aerial and boat tracking surveys, and from tag returns by anglers. All fish located in the mainstem or a tributary stream and fish known to be harvested (tag was returned) were assigned fate number three. All fish whose radio tags were located within 5 km of the capture site for 30 days after tagging were assigned fate number one. Chinook salmon whose radio tags were located only downstream of Horseshoe Bend for more than 30 days after tagging were inferred to be fish that had succumbed to handling mortality (fate number two).

Recapture Sample

There were 2 recapture events conducted for the mark–recapture study, one of which entailed sampling Chinook salmon at a weir on Big Creek from June through September. Most Chinook salmon passed through a narrow chute and individual fish were recorded on video and counted. A fixed tracking station positioned at the weir identified all radiotagged fish that passed through the weir. Because external tags were visible on video recordings, the number of visually observed marked fish could be compared to the number of marked fish recorded by the fixed station. The total number of Chinook salmon counted passing the weir was considered the second population sample (C_{BC}) (the first sample was the marked sample (M) captured by gillnets in the lower Naknek River). The number of recaptured marked fish (R_{BC}) was the total number of radiotagged fish passing by the weir that were detected by the fixed station during the sampling period. A maximum of 162 Chinook salmon were sampled from the live trap at the weir each week to estimate ASL compositions. These data were used to test model assumptions of equal capture probabilities.

The second recapture event (from 1 August until 15 August) occurred at a time when fish "hold" in prespawning aggregations and was located on the mainstem of the Naknek River between Rainbow Bend and Shawbeck's cabin where Chinook salmon have been historically observed during aerial spawning escapement surveys. This area was approximately 5 km above the confluence of Big Creek, minimizing the chance of capturing mixed spawning stock. Chinook salmon were captured with the same drift gillnets used during the marking event. All captured Chinook salmon were examined for the presence of a Floy tag and/or Peterson disc tag, a radio tag, and a hole punch through the middle of the dorsal fin indicating it had been previously sampled. Tag number, type, and color were recorded and before release, each fish was marked with a hole-punch as indicated above. A fish recaptured with this mark was not included in the recapture data. The samples for this recapture event were the total number of Chinook salmon examined for a tag (C_{MS}) and the total number of tagged fish (R_{MS}) recaptured.

Initially, all captured Chinook salmon were measured (MEF length), sex was determined, and scales were removed for aging as described for the marking event. However, fish were easily captured so a minimum of 30 fish were sampled each day to ensure that composition data would be collected for a minimum of 325 salmon during the mainstem recapture event.

Conditions for a Consistent Petersen Estimator

For the estimate of abundance from this mark–recapture experiment to be unbiased, certain conditions needed to be fulfilled (Seber 1982). The conditions, expressed in the circumstances of this study, along with their respective design considerations, test procedures, and necessary adjustments for significant test results are listed below.

Marking and handling did not affect the ability to recapture Chinook salmon.

There was no explicit test for this assumption because the behavior of unhandled fish could not be observed. However, holding and handling time of all captured Chinook salmon was minimized in this study. Furthermore, any obviously stressed or injured fish was not tagged. Tagged fish that were located only downstream of Pauls Creek (and that were never documented migrating upriver) were removed from the experiment. The time it took for a tagged fish to move from the capture site to a tracking station on a tributary or the mainstem river at Rainbow Bend was recorded by the station. John Eiler (National Marine Fisheries Service, Juneau, personal

communication) found that chum salmon tagged and released immediately after capture resumed upriver movement faster and traveled farther upriver than fish that had been held prior to release, indicating that tagging does not impede upriver migration.

All Chinook salmon had the same probability of being caught in the first sample or in the second sample; or, marked fish completely mixed with unmarked fish between samples.

Design Considerations: Tagging was conducted over the entire span of the run. Tags were implanted into Chinook salmon of various sizes and Chinook salmon captured along both banks and the midchannel of the river. Recovery sampling was conducted over the span of the run over a broad geographic area including a tributary and the mainstem of the Naknek River. Sex and length were recorded for all tagged fish as was date and time of release. For the recapture events, ASL data were collected from a sample of fish passing through the weir or captured in the mainstem. Because both banks and the midchannel of the river were sampled during both the marking event and the recapture event on the mainstem, mixing across the river could be investigated; bank of capture and location of recapture were recorded for all fish.

Test: Equal probability of capture was evaluated by size, sex, time, and area. Size-selective sampling was tested using Kolmogorov-Smirnov (K-S) tests (Conover 1980) to compare cumulative length distributions of 1) all fish marked during the first sampling event, 2) tagged fish that passed through the weir or were recaptured with nets upriver, and 3) all fish sampled in the recapture events (by each recapture event and pooled). Sampling of salmon at the Big Creek weir was conducted using a temporally stratified design, and individual fish were weighted based on the sampling intensity within each time stratum. Distributions of weighted observations were compared to other samples using a randomization test (Manly 1997) for the K-S test statistic, and distributions using unweighted samples were compared using the conventional K-S test. The tests and possible actions for data analysis are described in Appendix A1.

Sex-selective sampling was tested using contingency table analysis (Conover 1980) to compare ratios of males and females observed in the unweighted samples described above. When stratified (weighted) data from the Big Creek weir were compared to other sampling events, empirical Bayesian methods (Carlin and Louis 2000) were used to evaluate the differences between estimated percent females between samples. Using Markov chain Monte Carlo (MCMC) techniques, posterior distributions for these differences were generated by modeling unweighted data from the first sampling event and the mainstem event using a binomial model and for the Big Creek event using a multinomial model for data from each time stratum. Credibility intervals (95%) for differences that excluded zero resulted in differences being considered statistically significant. Interpretation of tests and possible actions for stratification prior to data analysis followed logic similar to that described for size-selective sampling in Appendix A1.

Equal catchability by time during second event sampling was tested by comparison of recapture rates (R/M) by time period of capture using contingency-table analysis. In addition, recapture rates for fish marked on each bank were compared using contingency table analysis.

Marked to unmarked ratios at the weir and mainstem were compared using contingency table analysis to evaluate equal probability of capture over time (consistency in marking later mainstem and earlier tributary spawning stocks) during the first event sampling.

<u>Adjustments:</u>

1) If the tests indicated sex or size selectivity, stratified estimates of abundance were calculated if necessary and these stratified estimates were summed to estimate total abundance.

2) If no significant difference was detected in recapture rates by time period of tagging and no significant difference was detected in recapture rates by bank of tagging, a Chapman-type model (described below) was used to estimate abundance. If recapture rates were not independent of when or where fish were marked, we tested for consistency in marked:unmarked ratios between different temporal and bank-of-tagging recapture strata.

3) If we detected no differences in marked:unmarked ratios between recapture strata, a Chapman-type model was used. A difference in marked to unmarked ratios at the weir or on the mainstem was likely a result of either unequal probability of capture by time (temporal differences in run timing and capture probabilities), or a difference in probabilities of capture by bank (bank-oriented migrations). Either a temporal or bank-of-tagging stratified estimator such as the method of Darroch (1961) was used to estimate abundance with either scenario. Consecutive strata (periods) that have similar recapture rates were pooled.

Tagged fish moving past the weir were known completely.

Fixed stations placed at the weir and at the lower end of the mainstem spawning location, in conjunction with aerial survey tracking flights of the river above the weir and on the mainstem spawning grounds, should have accounted for all tags at the recapture sites.

Tagged fish did not lose their tags between the tagging site and the weirs.

A combination of fixed tracking stations and aerial and boat tracking surveys were used to identify expelled radio tags. In addition, fish inspected at the weir and mainstem were examined for both a Floy/Peterson tag and a radio tag.

<u>Adjustment:</u> All tags that were expelled were culled from the analysis.

DATA ANALYSIS

Abundance

A 2-sample mark–recapture model was used to estimate the abundance of Big Creek and mainstem spawning Chinook salmon. The appropriate abundance estimator depended on the results of the aforementioned tests. If stratification was not needed, then a Chapman modification to the Petersen estimator (Seber 1982) was used:

$$\hat{N} = \frac{(C+1)(M+1)}{R+1} - 1 \tag{1}$$

where

$\hat{N}$ = estimated abundance of Chinook salmon returning to spawning locations at recapture sites in the Naknek River,

M = the number of radiotagged Chinook salmon known to survive tagging and handling,

C = the total number of Chinook salmon counted past the weir (C_{BC}) plus the total number examined for tags in the mainstem spawning grounds (C_{MS}) and,

R = the number of radiotagged Chinook salmon that moved past the weir (R_{BC}) plus the number of radiotagged salmon captured in the mainstem spawning grounds (R_{MS}).

For Big Creek, only actual counts, either seen on video recordings or counted in the live trap, were used as data (C_{BC} or R_{BC}) for the second sampling event. Radiotagged fish that passed through the Big Creek weir on days when water visibility precluded counting were not considered recaptured fish (R_{BC}). If possible, when water visibility become poor or when there were temporary problems with the video, fish were manually passed and counted through the trap box.

If stratification by size or sex was required, estimates for each stratum were generated using the estimator above and these estimates were summed to estimate total abundance. If stratification was required, C was estimated from composition data collected at the weir and in the mainstem. Variance and 95% credibility interval for the estimator (equation 1) were estimated using empirical Bayesian methods (Carlin and Louis 2000). Using MCMC techniques, posterior distributions for $\hat{N}$ (and for $\hat{N}_s$ if sex or size stratification was necessary) were generated by collecting 100,000 simulated values of $\hat{N}_s$ and $\hat{N}$ which were calculated using equation 1 from simulated values of equation parameters. The number of recaptures (R or stratified Rs) was modeled as a binomial function of the number of marked fish (M or stratified Ms). If sex or size stratification was necessary, the C_{BC} values were modeled as multinomial functions of C_{BC} for each of the temporal sampling strata at the weir and summed, and the C_{MS} values were modeled as a multinomial function of C_{MS}.

If bank-of-tagging or temporal stratification was required, estimates were calculated using the methods of Darroch (1961).

Age, Sex, and Length Composition

The proportion of Chinook salmon by ocean age or sex in the first sample of the two-sample mark–recapture experiment was calculated using

$$\hat{p}_k = \frac{n_k}{n} \qquad (2)$$

where

$\hat{p}_k$ = the estimated proportion of Chinook salmon in (sex or ocean age) group k,

n_k = the number of samples of a given sex or age group k, and

n = the total number of Chinook salmon sampled.

The variance was estimated as

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1 - \hat{p}_k)}{n - 1} \qquad (3)$$

Mean lengths and associated variances were calculated for each sex or age class k using

$$\bar{l}_k = \frac{\sum_{i=1}^{n_k} l_{i,k}}{n_k} \quad \text{and} \qquad (4)$$

$$\hat{V}[\bar{l}_k] = \frac{\sum_{i=1}^{n_k}(l_{i,k} - \bar{l}_k)^2}{n_k(n_k - 1)} \tag{5}$$

where

$l_{i,k}$ $\quad$ = $\quad$ length of salmon i in group k.

The estimated abundance of age or size class k was then estimated by

$$\hat{N}_k = \hat{p}_k \hat{N}. \tag{6}$$

The variance for $\hat{N}_k$ in this case was estimated using (Goodman 1960):

$$\hat{V}[\hat{N}_k] = \hat{V}[\hat{p}_k]\hat{N}^2 + \hat{V}[\hat{N}]\hat{p}_k^2 - \hat{V}(\hat{p}_k)\hat{V}(\hat{N}). \tag{7}$$

The formulas listed above assume an estimator that is not stratified with respect to sex or size. If a stratified estimator (by sex or size) was used, size and age proportions and variances of proportions were estimated using

$$\hat{p}_k = \sum_{s=1}^{j} \frac{\hat{N}_s}{\hat{N}} \hat{p}_{sk} \quad \text{and} \tag{8}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}^2}\left(\sum_{s=1}^{j} \hat{N}_s^2 \hat{V}[\hat{p}_{sk}] + (\hat{p}_{sk} - \hat{p}_k)^2 \hat{V}[\hat{N}_s]\right) \tag{9}$$

where

j $\quad$ = $\quad$ the number of sex/size strata,

$\hat{N}_s$ $\quad$ = $\quad$ the estimated abundance in stratum s,

$\hat{N}$ $\quad$ = $\quad$ the estimated total abundance, and

$\hat{p}_{sk}$ $\quad$ = $\quad$ the estimated proportion of fish that were age or size k among fish in stratum s (see equations (2) and (4)).

RESULTS

2003

Mark–Recapture Experiment

Marking Event

From 1 June through 31 July a total of 277 Chinook salmon were captured of which 243 were each tagged with a radio transmitter (Appendix B1, Table 1). The first Chinook salmon was captured on 14 June, but daily captures of Chinook salmon did not occur until 20 June (Appendix B1). Gillnets were drifted for a total of 204.2 hours, resulting in a mean catch per unit effort (CPUE) of 1.36 Chinook salmon per hour (Appendix B1). Each mesh size was fished a similar amount of time (100 hours for the 5.5-in mesh and 104 hours for the 7.5-in mesh). The 5.5-in mesh had a CPUE of 1.30 Chinook salmon per hour and the 7.5-in mesh had a CPUE of

1.42 Chinook salmon per hour. CPUE of Chinook salmon for each week of the capture event ranged from 0 for the first week of June to 3.12 for the week of 7 July (Table 2). CPUE of Chinook salmon by location of capture within the river varied slightly. CPUE for the left bank was 1.33 fish per hour (total hours drifted was 67), CPUE for the right bank was 1.42 fish per hour (total hours drifted was 74.8), and CPUE for the middle channel was 1.31 fish per hour (total hours drifted was 62.4).

Fates of Radiotagged Fish

Of the 243 radiotagged fish, 122 were detected at a spawning destination (Table 3). Eleven tagged fish were located in Pauls Creek and 11 in King Salmon Creek. Twelve tagged fish were located in Big Creek, 8 past the weir and 4 below the weir. Eighty-eight tagged fish were located in the mainstem of the Naknek River, 66 of which were in the recapture area during the mainstem recapture event (6 of which were recaptured in gillnets). The remaining 22 were located below the recapture area and were likely still moving up river to spawning sites.

Nonvalid tags (fish removed from the mark–recapture analysis) included fish assigned fates one, two, and four (Table 3) as well as those that migrated to Pauls and King Salmon creeks (see below). Fourteen fish expelled radio tags (fate one), 38 fish were handling mortalities (fate two), and 65 fish were not located or left the river (fate four). An additional 4 fish were assigned fate four due to harvest by commercial (3 fish) and sport (1 fish) fisheries.

Recapture Event - Big Creek Weir

The total passage of Chinook salmon past the Big Creek weir was 10,063 fish, of which 722 Chinook salmon were sampled for age, sex, and length (ASL) (Anderson et al. 2004). Eight tagged fish were documented past the Big Creek weir between the dates of 9 July and 9 August. These fish were recorded on the tracking station data logger at the weir and 7 of these fish were observed on video by USFWS staff. The remaining fish was sampled in the trap box at the weir. The sex ratio of fish recaptured at the weir was 7 males to 1 female (Table 1).

Recapture Event - Mainstem Netting

A total of 1,527 Chinook salmon, including 6 recaptured tagged fish, were captured from 1 August through 15 August. Five of the 6 recaptured fish were males. Chinook salmon were easily captured with gillnets. High concentrations of prespawning fish often resulted in the capture of multiple fish immediately after net deployment. This resulted in many drifts of less than 1 minute. As a result, the number of sets, but not the duration of drifts, was recorded each day. A total of 182 sets were made with 5.5-in mesh and 762 Chinook salmon were captured including 3 recaptures. A total of 179 sets were made with 7.5-in mesh and 574 fish were captured including 2 recaptures. A total of 13 sets of beach seines were used for 2 days resulting in the capture and measurement of 191 Chinook salmon including 1 recapture. An additional 206 jacks less than 450 mm METF length were captured with a beach seine, but not measured.

Abundance Estimate

The smallest recaptured radiotagged fish was 490 mm. We removed 1 of the 122 radiotagged fish with a known spawning destination from our analyses because all capture information (sex, length, time, and bank of tagging) was misplaced or not recorded. Inspection of spawning locations of radiotagged fish indicated a severe sampling bias during the marking event. The numbers of radiotagged salmon spawning in Pauls Creek (11), King Salmon Creek (11) and Big Creek (12) were very similar, contrasting with our inspection of several years of aerial survey

counts where approximately 3%, 10%, and 30% of the total Naknek River system aerial counts are typically observed in these drainages, respectively (Sands et al. 2003). We speculate that it is likely that we were catching and marking disproportionately more Pauls Creek "spawners" than fish destined for other spawning sites in the system. As a result, we removed fish that were located in Pauls Creek and King Salmon Creek from our analyses (leaving 99 fish for analyses) and attempted to estimate abundance of Naknek River Chinook salmon that spawned in areas above the confluence of King Salmon Creek.

We conducted our initial diagnostic testing using 99 radiotagged fish (*M*) and fish from second event samples (C_{MS}, or C_{BC}, including recaptures *R* from both R_{MS}, and R_{BC} to test for bias in the first event) for fish that were 490 mm and larger (Table 1). The proportions of males and females varied significantly between samples, indicating potential sampling bias in marking and recovery events. We found significant differences when comparing sex ratios between the marked sample and all recaptured fish (*M* vs. *R*; $\chi^2 = 5.20$, $P = 0.023$), the marked sample and the mainstem second event sample (*M* vs. C_{MS}; $\chi^2 = 6.43$, $P = 0.011$), all recaptured fish and the Big Creek second event sample (*R* vs. C_{BC}; $P_{MCMC} = 0.021$), and between the mainstem and Big Creek second event samples (C_{MS} vs. C_{BC}; $P_{MCMC} = 0.015$). We did not detect significant differences when comparing all recaptured fish with the mainstem second event sample (*R* vs. C_{MS}; $\chi^2 = 2.38$, $P = 0.123$) or the marked sample with the Big Creek second event sample (*M* vs. C_{BC}; $P_{MCMC} = 0.288$), however combined results of these tests indicate potential for bias. The ratio of recaptured males:females (12:2) was a factor in most, but not all of the differences detected, and we suspected that other differences could be a result of differential vulnerability of smaller age-1.1 and -1.2 males to our sampling gear. A tabular inspection of lengths of aged salmon from the mainstem recapture event indicated that 640 mm was a useful length to discriminate between age-1.2 and -1.3 salmon. Approximately 14% of the age-1.2 salmon were greater than 640 mm in length and approximately 14% of the age-1.3 salmon were less than 640 mm in length.

We conducted further diagnostic tests using 91 radiotagged fish and fish from second event samples that were 640 mm and larger (Table 1). When testing for gender bias, we found significant differences when comparing sex ratios between the marked sample and all recaptured fish (*M* vs. *R*; $\chi^2 = 5.66$, $P = 0.017$), all recaptured fish and the mainstem second event sample (*R* vs. C_{MS}; $\chi^2 = 6.51$, $P = 0.011$), and between all recaptured fish and the Big Creek second event sample (*R* vs. C_{BC}; $P_{MCMC} = 0.005$), however no differences were detected when comparing the marked sample and the mainstem second event sample (*M* vs. C_{MS}; $\chi^2 = 0.12$, $P = 0.725$), the marked sample and the Big Creek second event sample (*M* vs. C_{BC}; $P_{MCMC} = 0.874$), or the mainstem and Big Creek second event samples (C_{MS} vs. C_{BC}; $P_{MCMC} = 0.371$). The ratio of recaptured males:females (11:2) was a factor in the differences detected in the first 3 tests presented above and these results, when viewed without considering the last 3 tests, suggests that gender-biased sampling occurred during both marking and recovery events. When the results from the last 3 tests are considered, the most direct interpretation is that exactly the same nature of gender-biased sampling occurred during the marking event and at both sampling sites during second event sampling. However, we consider this interpretation to be improbable because 3 different gear types were used at the different sampling sites. Alternatively, the observed proportion of females in the sample of 91 radiotagged fish was 0.51 and the estimated proportions of females vulnerable to sampling during mainstem and Big Creek weir recovery sampling were 0.49 and 0.52, respectively (Table 1). These proportions, when considered with the observed proportion of radiotagged females recaptured (0.15), suggests that up to 5 to 6 times as many females as males 640 mm or larger were present in the spawning population than is

predicted by the recapture proportion, and that females were only 1/5 to 1/6 as likely to be sampled during each secondary sampling event. We judged that this recapture bias was unlikely, especially considering that gender biases of similar magnitude were found using both the Big Creek weir sampling protocols and the mainstem recovery sampling protocols (the ratios of males to females in the second sampling events at the mainstem and Big Creek were 948:419 [31% females] and 519:198 [28% females], respectively). This supports the idea that the second event sampling was not biased, but may have reflected a difference in behavior between sexes after the marking event. Thus, we opted to treat the 11:2 male:female ratio observed in the recapture sample as a statistical anomaly, due to small sample size and to assume that substantial gender bias for fish 640 mm and larger did not occur during our sampling efforts.

Next, we conducted diagnostic tests for size bias during sampling for fish 640 mm and larger. We compared the cumulative length distributions of marked and recaptured fish (M vs. R: K-S = 0.363, $P = 0.077$) and concluded that we had some potential for size bias during second event sampling, but that it was not significant. We did not detect significant size bias in sampling during the marking event when we compared recaptured fish with second event fish sampled in the mainstem (R vs. C_{MS}: K-S = 0.174, $P = 0.828$) and fish sampled at the Big Creek weir (R vs. C_{BC}: K-S = 0.196, $P = 0.688$). However, we found significant differences when comparing the marked sample to fish sampled during the recovery event (M vs. C_{MS}: K-S = 0.223, $P < 0.001$; and M vs. C_{BC}: K-S = 0.288, $P < 0.001$), which is consistent with our conclusion that size-biased sampling occurred during second event sampling efforts. Because no evidence of size-biased sampling was detected during our first (marking) event, size stratification was not necessary prior to estimating abundance.

We also tested for temporal and bank-of-tagging violations of equal probability of capture during first and second sampling events. We tested the null hypothesis that bank of capture during the tagging event (left bank, right bank, middle of channel) was independent of the probability that a radiotagged fish was recaptured, and failed to reject this hypothesis ($\chi^2 = 2.175$, df = 2, $P = 0.337$). Visual inspection of the data indicated that the probability that a marked fish was recaptured was higher for fish marked earlier during the marking event. We tested the null hypothesis that the probability that a marked fish was recaptured was independent of whether it was marked on 8 July or before versus being marked on 9 July or later, we rejected the null hypothesis ($\chi^2 = 24.887$, df = 1, $P < 0.001$). This result indicates that the probability of capture was not uniform throughout second event sampling. Because we did not have an exact enumeration of fish 640 mm or larger that passed the Big Creek weir, we used an estimated count of these fish to compare the marked:unmarked ratios of fish sampled at the weir versus those sampled during the mainstem recovery event. Test results are, at best, approximate but provide a strong indication that the proportions of marked fish were not similar in the 2 recovery areas ($\chi^2 = 3.560$, df = 1, $P = 0.059$). We interpreted this test result to indicate that the probability of capture was likely not uniform throughout the marking event. We did not conduct a test for complete mixing because sample sizes were too small for reliable contingency table analysis and inspection of the data indicated complete mixing was improbable. Under these conditions, the partially stratified estimator described by Darroch (1961) was necessary to estimate abundance.

The estimated abundance of Chinook salmon 640 mm and larger spawning in Big Creek and the mainstem Naknek River in 2003 was 20,558 (SE = 6,283). The estimated number of these

salmon spawning in Big Creek, both above and below the Big Creek weir, was 4,592 (SE = 1,372). The estimated number of mainstem spawners was 15,966 (SE = 5,994).

Age, Sex, and Length Compositions

The length distribution of Chinook salmon captured during the marking event ranged from 490 mm to 1,050 mm (Figure 3). The numbers of males and females were similar (139:138) and males had a mean length of 791 mm (SE = 12.2), while females had a mean length of 852 mm (SE = 6.8). We aged 233 Chinook salmon from the marking event. The modal age class of both males and females was 1.3 (Figure 4).

The length frequency distribution of Chinook salmon sampled at the Big Creek weir ranged from 310 mm to 1,030 mm (Figure 5). Excluding 5 fish of unknown sex, the male to female ratio was skewed toward males (519:198; proportion male = 0.72) with a high proportion (0.36) of males less than 500 mm. The mean length of males was 561 mm (SE = 8.37) whereas the mean length of females was 806 mm (SE = 8.87). We aged 615 Chinook salmon from the Big Creek capture event. The age distribution of males was comprised of a large proportion of jacks age of 1.1 (0.39) and 1.2 (0.22); the modal age class of females was 1.4 (Figure 6).

The length distribution of Chinook salmon captured with gillnets and excluding 31 fish that were captured twice during the mainstem recapture event ranged from 275 mm to 1,100 mm (Figure 7). The male to female ratio of these fish was skewed towards males (948:419; proportion male = 0.69) and males had a mean length of 633 mm (SE = 5.7), while females had a mean length of 864 mm (SE = 2.6). We aged 310 Chinook salmon from the mainstem capture event. The modal age class of males and females was 1.3 (Figure 8)

Migratory Timing and Bank Orientation

Telemetry data indicated that fish destined for different spawning locations entered the Naknek River at different times and exhibited a difference in bank orientation. Fish destined for Pauls and King Salmon creeks generally entered the river the earliest, followed by Big Creek fish, while mainstem spawning fish entered the river the latest (Table 4). On average, a tagged Chinook salmon passing by the fixed tracking station at the tagging area took 0.4 days to reach the fixed station at Pauls Creek, 6.7 days to reach the station at King Salmon Creek, 17 days to reach the weir on Big Creek and 6.5 days to reach the fixed station on the upper Naknek River mainstem (Figure 9).

The proportions of Chinook salmon using the left bank, right bank, and midchannel were determined for the 4 major spawning sites of the Naknek River. Fish destined for Pauls and King Salmon creeks were captured most frequently on the left bank (proportions 0.55 and 0.73, respectively) (Table 5). Fish destined for Big Creek were captured most frequently on the right bank (proportion 0.50) and mainstem spawning fish were captured most frequently in midchannel (proportion 0.37) (Table 5).

2004

Mark–Recapture Experiment

Capture Event

From 14 June through 30 July, 850 Chinook salmon were captured of which 312 were each tagged with a radio transmitter (Appendix B2; Table 1). Sampling with drift gillnets was

conducted for 155.4 hours for a CPUE of 5.47 Chinook salmon per hour. Each mesh size was fished a similar amount of time (71.60 hours for the 5.5-in mesh and 83.8 hours for the 7.5-in mesh). The 5.5-in mesh had a CPUE of 5.94 Chinook salmon per hour and the 7.5-in. mesh had a CPUE of 5.10 Chinook salmon per hour. CPUE of Chinook salmon for each week of the capture event ranged from 1.97 for the first week of June to 8.13 for the week of 28 June to 4 July (Table 6). CPUE of Chinook salmon by bank of tagging varied slightly with 5.73 fish per hour (53.8 total hours drifted) for the left bank, 5.93 fish per hour (55.3 total hours drifted) for the right bank and 4.62 fish per hour (46.3 total hours drifted) for the middle channel.

Fates of Radiotagged Chinook Salmon

Of the 312 radiotagged fish, 221 were detected at a spawning destination (Table 3). Sixty-two tagged fish were located in Pauls Creek and 59 were located in King Salmon Creek. Thirty-seven tagged fish were located in Big Creek, 31 past the weir and 6 below the weir. Sixty-three tagged fish were located in the mainstem, 52 of which were in the recapture area during the mainstem recapture event. The remaining 11 were located below the recapture area and were likely still moving up river to spawning sites. Two fish with transmitters were recaptured in the mainstem recapture area. Chinook salmon tagged with a transmitter and located in Big Creek above and below the weir, at the mainstem recapture site, and located in the mainstem but downstream of the recapture area during the recapture event were included in the mark–recapture experiment.

Nonvalid tags (fish removed from the mark–recapture analysis) included fish assigned fates one, two, and four (Table 3) as well as those that migrated to Pauls Creek and King Salmon Creek (see below). Seventeen fish expelled radio tags (fate one), 17 fish experienced handling mortality (fate two), and 52 fish were not located or left the river (fate four) (Table 3). An additional 5 fish were assigned fate four due to harvest by commercial (3 fish) and sport (2 fish) fisheries. These fish were not included in the estimation of abundance.

Recapture Event - Big Creek Weir

The total passage of Chinook salmon past the Big Creek weir for 2004 was 11,906 and a total of 288 Chinook salmon were sampled for ASL (Anderson 2005). Thirty-one tagged fish were documented passing the Big Creek weir between the dates of 28 June and 7 August. These fish were recorded on the data logger at the weir and 18 of these fish were observed on video by USFWS staff. The sex ratio of fish recaptured at the weir was 19 males to 12 females.

Recapture Event - Mainstem Netting

A total of 2,578 Chinook salmon including 6 recaptured tagged fish were captured from 1 August through 15 August (Table 1). Two of the 6 recaptured fish were tagged with transmitters. Two of the fish were males and 4 were females. Similar to 2003, Chinook salmon were easily captured with gillnets; as a result, the number of sets each day was recorded and the duration of drifts was not recorded. There were 350 sets with 5.5-in mesh and 1,394 Chinook salmon were captured including 3 recaptures. There were 373 sets with 7.5-in mesh and 1,184 fish were captured including 3 recaptures.

Abundance Estimate

The smallest radiotagged fish that was not removed from analysis based on fate categories one, two, and four was 540 mm. Therefore, fish larger than 539 mm were included in the consistency tests and estimate of abundance. Similar to the 2003 experiment, inspection of spawning locations of radiotagged fish indicated a sampling bias during the marking event, with

disproportionately high numbers of Pauls Creek and King Salmon Creek "spawners" receiving radio tags. These fish were removed from the analyses and we attempted to estimate abundance of Naknek River Chinook salmon that spawned in areas above the confluence of King Salmon Creek.

We conducted our diagnostic testing using 100 radiotagged fish from second event samples that were 540 mm or larger (Table 1). We detected no evidence of gender-biased sampling during any sampling event. When testing for gender bias, we found no significant differences when comparing sex ratios between the marked sample and all recaptured salmon (M vs. R; $\chi^2 = 0.21$, $P = 0.643$), all recaptured salmon and the mainstem second event sample (R vs. C_{MS}; $\chi^2 = 2.04$, $P = 0.153$), the marked sample and the mainstem second event sample (M vs. C_{MS}; $\chi^2 = 2.40$, $P = 0.121$), all recaptured salmon and the Big Creek second event sample (R vs. C_{BC}; $P_{MCMC} = 0.378$), the marked sample and the Big Creek second event sample (M vs. C_{BC}; $P_{MCMC} = 0.582$), and between the 2 second event samples (C_{MS} vs. C_{BC}; $P_{MCMC} = 0.257$). We concluded that we had no need to stratify by gender to estimate abundance or biological compositions.

We next conducted diagnostic tests for size-biased sampling for fish 540 mm and larger. We compared the cumulative length distributions of marked and recaptured fish (M vs. R: K-S = 0.258, $P = 0.057$) and concluded that we had some potential for size bias during second event sampling, but that it was not significant. We detected significant evidence of size-biased sampling during the marking event when comparing recaptured fish with second event fish sampled in the mainstem (R vs. C_{MS}: K-S = 0.376, $P < 0.001$). However, no significant difference was detected when comparing recaptured fish with fish sampled at the Big Creek weir (R vs C_{BC}: K-S = 0.110, $P = 0.921$). We found significant differences when comparing the marked sample to fish sampled during both the mainstem and Big Creek second events (M vs. C_{MS}: K-S = 0.168, $P = 0.009$; and M vs. C_{BC}: K-S = 0.239, $P = 0.003$). The significant difference between the marked and mainstem samples could be no more than a reflection of size bias during the marking event as indicated by the difference between the recaptured salmon and the mainstem sample, however there was no difference between the marked and Big Creek samples suggesting a second event size bias, especially when the marked and recaptured salmon are compared. When we compared the second event samples from the mainstem and Big Creek (C_{MS} vs. C_{BC}: K-S = 0.336, $P < 0.001$), we concluded that either the distribution of fish lengths was different at the 2 locations or that the different sampling methods resulted in different vulnerability to sampling of different sizes of fish. Based on these results, we stratified our data into 2 size strata: fish 540–814 mm and fish 815 mm and larger.

We tested for further indications of size-biased sampling within these 2 strata. For the stratum containing fish 540 mm to 814 mm in length, we detected no significant evidence of size-biased sampling during either the first event (R vs. C_{MS}: K-S = 0.202, $P = 0.260$; R vs. C_{BC}: K-S = 0.167, $P = 0.668$) or the second event (M vs. R: K-S = 0.109, $P = 0.952$). Similarly, for the stratum containing fish 815 mm and larger we detected no significant evidence of size-biased sampling during either the first event (R vs. C_{MS}: K-S = 0.340, $P = 0.313$; R vs. C_{BC}: K-S = 0.217, $P = 0.912$) or the second event (M vs. R: K-S = 0.189, $P = 0.928$). We concluded that this stratification was sufficient to minimize the potential for bias when estimating abundance.

We also tested for temporal and bank-of-tagging violations of equal probability of capture during first and second sampling events. We tested the null hypothesis that bank of capture during the tagging event (left bank, right bank, midchannel) for fish 540 mm and larger was independent of the probability that a radiotagged fish was recaptured, and did not find strong evidence to reject

this hypothesis (χ^2 = 4.89, df = 2, P = 0.087). However, nominal recovery rates for fish tagged on the left bank (0.22 fish per h) and midchannel (0.25 fish per h) were similar but different than for fish tagged on the right bank (0.44 fish per h). When left bank and midchannel fish were pooled and compared to fish tagged in the right channel we found significant evidence to reject the null hypothesis (χ^2 = 4.85, df = 1, P = 0.028) that probability of recapture was independent of bank of tagging. This result indicated that the probability of recapture was not equal among all fish. We also tested this hypothesis within each of the 2 size strata identified because if size bias were confounded with temporal or bank-of-tagging variation in probability of capture, it is possible that size stratification would be sufficient to eliminate the potential biases due to temporal or bank-of-tagging differences. When we tested the hypothesis that bank of capture during the tagging event for fish 540 mm to 814 mm was independent of the probability that a radiotagged fish was recaptured, we failed to reject the null hypothesis (χ^2 = 0.60, df = 2, P = 0.741). We also failed to reject the null hypothesis when comparing right bank fish with pooled left bank and midchannel fish (χ^2 = 0.51, df = 1, P = 0.473). When we tested the hypothesis that bank of capture during the tagging event for fish 815 mm and larger was independent of the probability that a radiotagged fish was recaptured, we failed to reject the null hypothesis (χ^2 = 3.41, df = 2, P = 0.181). Again, we failed to reject the null hypothesis when comparing right bank fish with pooled left bank and midchannel fish (χ^2 = 3.26, df = 1, P = 0.071), but interpret these results as indicating that within the larger size stratum of fish, we still have some potential for bias due to unequal probability of capture during the second sampling event.

Similar to 2003, visual inspection of the data indicated that the probability that a marked fish was recaptured was higher for fish marked earlier during the marking event. We tested the null hypothesis that the probability that a marked fish was recaptured was independent of whether it was marked on 4 July or before versus being marked on 5 July or later, we rejected the hypothesis (χ^2 = 30.17, df = 1, P < 0.001). Results were similar when testing the 540 mm to 814 mm size stratum (χ^2 = 14.16, df = 1, P < 0.001) and the 815 mm and larger size stratum (χ^2 = 12.75, df = 1, P < 0.001). These results indicate that the probability of capture was not uniform throughout second event sampling.

We did not have an exact enumeration of fish 540 mm or larger that passed the Big Creek weir. We used an estimated value of these fish to compare the marked:unmarked ratios of fish sampled at the weir versus those sampled during the mainstem recovery event. These test results are approximate and we failed to reject the null hypothesis that the proportions of marked fish were similar in the 2 recovery areas (χ^2 = 2.75, df = 1, P = 0.097). When we evaluated this hypothesis within size strata, we again failed to reject the null hypothesis for both fish 540 mm to 814 mm (χ^2 = 1.09, df = 1, P = 0.296) and fish 815 mm and larger (χ^2 = 1.14, df = 1, P = 0.286). We did not detect significant differences in probability of capture during the first event between fish that were recaptured at Big Creek and fish recaptured in the mainstem. As a result, the Chapman model (Seber 1982) could be used to estimate abundance, after stratifying data by size.

The Chapman modification to the Petersen estimator was used to estimate the abundance of Chinook salmon in each size stratum, and results were summed to produce an overall estimate of abundance of fish 540 mm and larger. Strata estimates were 17,481 (SE = 2,673) for fish 540 mm to 814 mm and 24,669 (SE = 8,639) for fish 815 mm and larger, summing to 42,151 (SE = 8,898) Chinook salmon 540 mm and larger. Of these, we estimated 14,450 (SE = 1,536) were Big Creek "spawners" and 27,701 (SE = 8,282) were mainstem "spawners." Using second event size composition data from the Big Creek weir and the mainstem sampling event, we estimated

the number of Chinook salmon 640 mm and larger spawning in Big Creek was 11,282 (SE = 1,513) and in the mainstem was 24,742 (SE = 8,087), summing to a total of 36,024 (SE = 8,725) Chinook salmon.

Age, Sex, and Length Compositions

The length distribution of 847 Chinook salmon captured during the marking event ranged from 460 mm to 1064 mm (Figure 10). The number of males and females was similar (413:434; proportion male = 0.49) and males had a mean length of 736 mm (SE = 6.54), while females had a mean length of 839 mm (SE = 2.69). We aged 759 fish from the marking event. The modal age class of males was 1.3 and the modal age class of females was 1.4 (Figure 11).

The length frequency distribution of 286 Chinook salmon sampled at the Big Creek weir ranged from 318 mm to 998 mm (Figure 12). The male to female ratio was 164:122 (proportion males = 0.57) and males had a mean length of 699 mm (SE = 10.93), while the mean length of females was 754 mm (SE = 10.74). Age was determined for 271 fish and the modal age class for males and females was 1.3 (Figure 13).

The length distribution of Chinook salmon captured during the mainstem recapture event with gillnets ranged from 304 mm to 1,078 mm (Figure 14). The male to female ratio was skewed towards males (1,415:1,137; proportion males = 0.55) and males had a mean length of 692 mm (SE = 4.50), while females had a mean length of 859 mm (SE = 1.7). Age was determined for 199 fish and the modal age classes of males was 1.2 and for females was 1.4 (Figure 15).

Migratory Timing and Bank Orientation

Telemetry data indicated that fish destined for different spawning locations entered the Naknek River at different times and exhibited a difference in bank orientation. Fish destined for Pauls and King Salmon creeks generally entered the river the earliest, followed by Big Creek fish while mainstem spawning fish entered the river the latest (Table 7). On average, a tagged Chinook salmon passing by the fixed tracking station at the tagging area took 3 days to reach the fixed station at Pauls Creek, 5.8 days to reach King Salmon Creek, 14.4 days to reach the weir on Big Creek and 6.7 days to reach the fixed station on the upper Naknek River (Figure 9).

The proportions of Chinook salmon using the left bank, right bank, and midchannel were determined for the 4 major spawning sites of the Naknek River. Fish destined for Pauls and King Salmon creeks were captured most frequently on the left bank (proportions 0.53 and 0.56, respectively) (Table 8). Fish destined for Big Creek and mainstem spawning fish were captured most frequently on the right bank (proportions 0.62 and 0.37, respectively) (Table 8).

DISCUSSION

This 2-year study estimated the abundance, size, age, and sex distributions of Chinook salmon at 2 spawning locations of the Naknek River drainage. In addition, the run timing of Chinook salmon destined for 4 spawning locations in the drainage was estimated from radiotelemetry data. Abundance estimates could not be derived for 2 spawning locations, Pauls and King Salmon creeks, because no recapture events were conducted on these tributaries. These tributaries have historically received a combined 13% of the escapement to the Naknek River (Sands et al. 2003), yet received 18% of the transmitters in 2003 and 55% of the transmitters in 2004, reducing the marked sample for this experiment. The short length of the Naknek River, our attempt to minimize interference with the sport fishery, and the presence of an inriver

commercial fishery made it difficult to capture fish in a manner that prevented a high proportion of the marks moving into the lower tributaries. The upper end of the capture and marking location for the study was approximately 0.8 km below the confluence of Pauls Creek and 8 km from the confluence of King Salmon Creek and fish destined for these tributaries showed a propensity for capture on the same bank (left) as the outlets to these tributaries. In addition, there was no feasible means of conducting a recapture event in Pauls or King Salmon creeks because all resources were used for the marking event and the mainstem recapture event.

During 2003, the marking objective of 300 fish was not met (246 fish) and the loss of tags for fish that dropped out of the river, were mortalities, or spawned in Pauls and King Salmon creeks reduced the number of marks available for recapture. This contributed to the fact that only 14 fish were recaptured in 2003. In 2004, the marking objective was met (312 fish) and more recaptures were obtained (37 fish). The combined proportion of tagged fish determined to have lost tags, were mortalities, or that were not located or left the river was higher in 2003 than 2004 (Table 3). The proportion of fish determined to have lost tags each year (0.06 in 2003 and 0.05 in 2004) was not unusually large when compared to the regurgitation rate of Chinook salmon in the Columbia River (proportion expelled = 0.03) (Keefer et al. 2004). However, the combined proportion of fish that were not located or did not migrate upriver (0.27) and the proportion of fish that were mortalities (0.15) appeared unusually high in 2003 when compared to other studies. Savereide (2005) estimated that 7% of radiotagged Chinook salmon did not migrate upriver during 3 years of tagging on the Copper River and similar results were found on the Stikine and Taku rivers (Pahlke and Bernard 1996; Bernard et al. 1999).

The reason there was a large proportion of fish that were not located or that left the river in 2003 was in part due to the low numbers of fish captured during the marking event and an inability to obtain the tagging goal, which reduced the ability to select only the fittest fish for tagging. Fish captured during the marking event that had slight bleeding or appeared stressed received a transmitter in the hopes that they would reach a spawning destination. This likely increased handling mortality and the occurrence of radiotagged fish moving down river for a period of time, which has been documented in other radiotagging studies (Johnson et al. 1992, 1993; Bendock and Alexandersdottir 1993; Pahlke et al. 1996; Bernard et al. 1999). A downstream movement increased the chance of harvest for radiotagged fish in the inriver commercial fishery that occurred during 2003 and 2004. In addition, 2 fish were captured in terminal commercial fisheries in different districts. During 2003, a tagged fish was harvested from the Togiak District, approximately 240 km from the Naknek River. In 2004, a tagged fish was harvested in the Ugashik District, approximately 110 km south of the Naknek River. These recoveries indicate that some Chinook salmon entering the Naknek River are likely destined for other systems, creating a source of tag loss.

In 2004, several factors contributed to higher survival and greater relocations of tagged fish. Aerators were used in the holding totes to reduce stress while fish were sampled and tagged. In addition, the Chinook salmon escapement in 2004 appeared much higher than 2003. The CPUE during the marking event in 2004 (5.47 fish per h) was much higher than 2003 (1.36 fish per h) despite sampling in the same area, at the same tide stage, and with the same gear. An increased number of marked fish and increased effort from 21 June to 7 July in 2004 probably led to a greater number of recaptures. Most of these recaptures occurred at the Big Creek weir, where nearly every fish passing the weir was visually examined for an external tag. In addition, radiotagged fish were detected by a fixed tracking station. However, the number of recaptures (2)

in the mainstem remained low despite the examination of over 2,500 fish for tags. Escapement of Chinook salmon to the mainstem spawning area appeared very high and fish were easily captured with drifted gillnets, but the 52 radiotagged fish tracked to the recapture area had a very low probability of capture because so many untagged fish were present.

Radio tags as the primary mark allowed for the explicit testing of tag loss, emigration, and mortality because the fates of radiotagged fish could be determined. If radio tags had not been used, it would have been impossible to determine the fates of tagged fish and the sources of tagged fish loss. Despite the loss of numerous fish to various fates, which reduced the precision of estimated abundance, radio tags provided knowledge of the number of fish to reach each recapture area and allowed us to estimate abundance at the 2 major spawning locations of the Naknek River in 2003 and 2004.

The Darroch (1961) estimator was employed to estimate abundance in 2003, removing potential bias due to bank-of-tagging and temporal variability in probabilities of capture. While our diagnostic tests indicated potential for bias in abundance estimation due to unequal probabilities of capture between males and females, we argued that such a disparity between males and females was very unlikely, particularly for fish 640 mm and larger, and elected not to stratify by gender before estimating abundance. If gender-biased sampling did occur, the abundance estimate we reported would be negatively biased and underestimate actual abundance.

A size stratified Chapman estimator (Seber 1982) was employed to estimate abundance in 2004, removing potential bias due to size selective sampling. Our diagnostic tests did not indicate that a Darroch (1961) type of estimator was required to remove potential bias due to bank-of-tagging or temporal variability in probabilities of capture. Our diagnostic tests indicated bank-of-tagging and/or temporal variability in probability of capture during the second event, but none was detected for first event sampling. However, the first event diagnostic tests are only approximate and our samples sizes fairly small, particularly for tests within size strata. Some potential may have been present for bias due to bank-of-tagging or temporal variability in capture probabilities during first event sampling that was not detected by our diagnostics. If unequal sampling probabilities were present, we cannot predict the direction of bias for our abundance estimate.

A goal of this study was to estimate total abundance for comparison to aerial index counts. Aerial spawning-ground surveys have been the most cost-effective means of monitoring Chinook salmon escapements on the Naknek River, but their usefulness is limited because of known uncertainty and the inconsistent relationship to actual abundance. Despite these limitations, it is assumed that changes in escapement from year to year are indicated by a proportional change in the index count. This study allowed for the comparison of estimated total abundance to aerial survey index counts for 2 years. The estimated abundance in the mainstem of the Naknek River in 2003 was 15,966 Chinook salmon larger than 640 mm and the aerial survey count during the peak of spawning was 4,150 Chinook salmon, approximately 26% of the estimated abundance. No aerial survey count was obtained on Big Creek in 2003 due to highly turbid water. The estimated abundance for the mainstem in 2004 was 24,742 Chinook salmon larger than 640 mm and the aerial survey count was 6,900 Chinook salmon, approximately 28% of the estimated abundance. The aerial survey was conducted after the peak due to poor weather, which resulted in almost half the count consisting of carcasses. As a result, the aerial survey count for 2004 is likely low and may not be appropriate for comparison to the estimate of total abundance. The aerial survey count above the weir on Big Creek was conducted during the peak in 2004 and was

3,552 Chinook salmon, approximately 31% of the estimated abundance of 11,282 fish larger than 640 mm.

Comparisons of aerial surveys to estimates of total abundance from mark–recapture studies and weir counts have been conducted on several rivers in Alaska. In Southeast Alaska, ADF&G peak aerial survey index counts have been compared to mark–recapture abundance estimates of Chinook salmon larger than 660 mm on several rivers for multiple years. The percent of the mark–recapture estimates observed have ranged from an average of 19% for the Taku River (7 years) (Pahlke 2004), 21% for the Chickamin River (6 years) (Weller et al. 2007), and 20% for the Unuk River (8 years) (Weller and McPherson 2006). Given the variability of aerial survey conditions for individual rivers and for temporally dependent weather and river conditions at the time of surveys, the Naknek River comparison of aerial survey data to estimated total abundance appears reasonable.

The results of this study give managers the ability to compare aerial survey index counts for 2 spawning locations for 2 years. It is not cost effective to conduct mark–recapture abundance estimates on an annual basis so expansion factors have been developed for rivers in Southeast Alaska by calculating the proportion of an estimate of total abundance that is counted during an aerial survey index. The utility of expanding historical counts by an expansion factor derived from these results for the Naknek River is questionable. Historic aerial surveys are affected by year-to-year variations in surveys, changes in the distribution of spawning salmon among tributaries, inclement weather, turbidity, and changes in pilot or observer experience. In addition, the comparison of the 2004 estimate of total abundance to the aerial survey is not entirely appropriate given the timing of the survey after the peak of spawning. More years of estimates of total abundance would be necessary to develop a reliable expansion factor.

The exploitation rate of the Naknek River drainage can not be estimated directly because the estimated abundance does not include fish destined for Pauls or King Salmon creeks. However, if it were assumed that the historic aerial survey index counts are representative of the spawning distribution of Chinook salmon to the Naknek River, the estimated total abundance can be expanded by 13% (the proportion destined for Pauls or King Salmon creeks) and exploitation can be estimated. Only the estimates of fish 640 mm and larger can be used to calculate exploitation because an estimate of fish smaller than this is not available for 2003. An increase in abundance by 13% yields abundances of 23,231 in 2003 and 40,707 in 2004. Harvest numbers for the commercial, subsistence (Westing et al. 2005), and sport fisheries (Jennings et al. 2007; Jennings et al. 2006b) are available for each year (Table 9). Estimated total exploitation for the Naknek River for 2003 and 2004 are 15% and 13% respectively. Factors that must be considered for the estimate of exploitation for these 2 years include a lack of knowledge of the size range of Chinook salmon harvested by each user group each year. For example, if many small Chinook salmon were harvested, the exploitation would be overestimated based on the calculation of abundance for fish larger than 640 mm. Based on this research, it is also possible that some of the Chinook salmon harvested may be destined for other drainages, which would overestimate the exploitation of Naknek River fish. Despite these caveats, exploitation based on the estimated abundance still provides a better understanding of Chinook salmon exploitation in the Naknek River than is available with the historic aerial survey index counts.

The Naknek River proved to be a challenging river to conduct a mark–recapture abundance estimate for Chinook salmon. The river is relatively short and supports 3 user groups that harvest Chinook salmon. An attempt was made to avoid conflicts with the user groups during the

marking and recapture events. The capture event could not be conducted in the lower 2.4 km of the river due to a wide channel with sand bars, an inriver commercial fishery, and subsistence fisheries. Upriver of Pauls Creek was popular with sport fishermen, which relegated the capture and tagging site to below Pauls Creek. In 2003, this area proved difficult to catch sufficient numbers of fish with drifted gillnets. Increased effort and a larger return of Chinook salmon aided in meeting sampling objectives for the marking event in 2004. The USFWS-operated weir on Big Creek, which was only operated for a 3-year period, provided a reliable recapture site for 1 spawning tributary in the drainage. However, due to a difference in run timing, an estimate of abundance for the mainstem of the Naknek River spawning population could not be obtained from an expansion of mark–recapture data from the weir without comparing the marked to unmarked ratio, and size and age compositions at each spawning location. As a result, a recapture event had to be devised for the mainstem spawning population. The only feasible means of obtaining a large sample size was by drifting gillnets for prespawning concentrations of fish, which was not perceived well by the public.

If this project were to be conducted in the future, several options should be considered. If an estimate of total inriver abundance is desired, the marking site could be moved farther down river in an attempt to minimize the inordinately high proportion of tags moving into Pauls and King Salmon creeks. However, the channel becomes less defined in the lower river making it more difficult for boat navigation and netting fish. If only estimates for Big Creek and the mainstem spawning populations are desired, the marking site could be moved above King Salmon Creek to the stretch of river in front of the ADF&G compound. This 2.4 km stretch of river is between popular sport fishing locations so interference with recreational anglers could be minimized. In addition, the site is approximately 8 km below Big Creek, which may allow for an unbiased distribution of marks among the 2 spawning sites.

ACKNOWLEDGMENTS

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TABLES

Table 1.–Numbers used in mark–recapture analyses.

Year	Variable	Quantity	Sex		Capture location		
			Males	Females	Left bank	Right bank	Mid channel
2003							
	Marking event	277	139	138	83	106	88
	Tagged	243	119	124	79	89	75
	Analyses including fish 490 mm or larger[a]						
	M	99	53	46	28	36	35
	R	14	12	2	6	5	3
	C	2089	1467	617			
	U	2075	1455	615			
Big Creek (BC)							
	C_{BC}	722 [b]	519	198			
	R_{BC}	8	7	1	4	3	1
	U_{BC}	714	512	197			
Mainstem (MS)							
	C_{MS}	1367	948	419			
	R_{MS}	6	5	1	2	2	2
	U_{MS}	1361	943	418			
	Analyses including fish 640 mm or larger[c]						
	M	91	45	46	25	35	31
	R	13	11	2	5	5	3
	C	1231	622	609			
	U	1218	611	607			
Big Creek (BC)							
	C_{BC}	322	155	167			
	R_{BC}	8	7	1	4	3	1
	U_{BC}	314	148	166			
Mainstem (MS)							
	C_{MS}	909	467	442			
	R_{MS}	5	4	1	1	2	2
	U_{MS}	904	463	441			

-continued-

Table 1.–Page 2 of 2.

Year	Variable	Quantity	Sex		Capture location		
			Males	Females	Left bank	Right bank	Mid channel
2004							
	Marking event	850	415	435	308	327	215
	Tagged	312	176	136	130	109	73
	Analyses including fish 540 mm or larger[d]						
	M	100	56	44	18	55	27
	R	37	21	16	8	22	7
	C	2866	1406	1460			
	U	2829	1385	1444			
	Big Creek (BC)						
	C_{BC}	288	166	122			
	R_{BC}	31	19	12	5	20	6
	U_{BC}	257	145	110			
	Mainstem (MS)						
	C_{MS}	2578	1338	1240			
	R_{MS}	6	2	4	3	2	1
	U_{MS}	2572	1336	1236			
	Estimated abundance 640 mm or greater						
	M	90	46	44	28	48	24
	R	31	15	16	8	18	5
	C	2106	692	1414			

Note: M = number of fish marked during the first event sample, R = number of recaptured (marked) fish from second event samples, C = number of fish caught in second event samples, U = number of unmarked fish captured during second event samples. Parameters without subscripts indicate totals from both Big Creek and the mainstem capture area. Parameters with subscripts indicate numbers counted only in a particular area.

[a] Includes diagnostic test for sex bias.

[b] Includes an additional 5 fish of unknown sex.

[c] Includes diagnostic tests for sex bias, size bias, temporal and locational bias, and estimated abundance.

[d] Includes diagnostic tests for sex bias, size bias, temporal and locational bias, and estimated abundance.

Table 2.–Number of Chinook salmon captured, gillnet effort, catch per unit effort (CPUE), and mean and median lengths (ln) by sampling week during the marking event in 2003.

	Week	Number of salmon captured	Gillnet effort (h)	CPUE (number/h)	Mean ln	SE	Median ln
1	1–8 June	0	28.10	0.00	ND	ND	ND
2	9–15 June	3	27.20	0.11	627	91.85	545
3	16–22 June	4	28.60	0.14	823	31.66	845
4	23–29 June	30	16.60	1.81	764	21.89	788
5	30 June–6 July	26	21.60	1.20	799	17.70	795
6	7–13 July	74	23.70	3.12	818	13.64	845
7	14–20 July	53	21.10	2.51	829	15.17	858
8	21–27 July	67	22.70	2.95	851	15.60	870
9	28–31 July	20	14.60	1.37	861	25.20	878
	All samples	277	204.2	1.36	797	26.44	821

Table 3.–Locations or fates of radiotagged Chinook salmon in the Naknek River, 2003–2004.

Fate category[a]	Location or fate	Number and percentage of tags			
		2003		2004	
		Number	Percentage	Number	Percentage
1	Expelled transmitter	14	6%	17	5%
2	Handling mortality	38	15%	17	5%
3	Big Creek	12	5%	37	12%
3	Naknek River	88	36%	63	20%
3	Pauls Creek	11	4%	62	20%
3	King Salmon Creek	11	4%	59	19%
4	Sport fishery mortality	1	0%	2	1%
4	Commercial fishery mortality	3	1%	3	1%
4	Left the Naknek River	27	11%	26	8%
4	Not located	38	15%	26	8%
	Total detected at spawning locations	122	50%	221	71%
	Total deployed	243	100%	312	100%

[a] Fate categories described in methods section.

Table 4.–Week of capture for Chinook salmon destined for the 4 major spawning sites of the Naknek River as determined by radio telemetry, 2003.

Week		Pauls Creek	King Salmon Creek	Big Creek	Upper Naknek River
1	1–8 June	0	0	0	0
2	9–15 June	0	1	0	0
3	16–22 June	2	0	0	0
4	23–29 June	4	4	4	3
5	30 June–6 July	5	4	3	1
6	7–13 July	0	2	3	23
7	14–20 July	0	0	2	13
8	21–27 July	0	0	0	32
9	28–31 July	0	0	0	16
	Total:	11	11	12	88

Table 5.–Bank of orientation for Chinook salmon destined for the 4 major spawning sites of the Naknek River as determined by radio telemetry, 2003.

Bank	Pauls Creek		King Salmon Creek		Big Creek		Mainstem	
	Number	Proportion	Number	Proportion	Number	Proportion	Number	Proportion
Left	6	0.55	8	0.73	4	0.33	25	0.29
Right	2	0.18	2	0.18	6	0.50	30	0.34
Midchannel	3	0.27	1	0.09	2	0.17	32	0.37
Total:	11	1.00	11	1.00	12	1.00	87	1.00

Table 6.–Number of Chinook salmon captured, gillnet effort, catch per unit effort (CPUE), and mean and median lengths (ln) by sampling week during the marking event in 2004.

	Week	Number of salmon captured	Gillnet effort (h)	CPUE (number/h)	Mean ln (mm)	SE	Median ln
1	14–20 June	48	24.40	1.97	719	16.33	751
2	21–27 June	172	27.50	6.25	777	8.05	798
3	28 June–4 July	204	25.10	8.13	782	7.12	808
4	5–11 July	147	20.90	7.03	781	10.20	808
5	12–18 July	122	20.70	5.89	793	10.73	823
6	19–25 July	98	21.80	4.50	838	9.76	858
7	26–30 July	59	15.00	3.93	833	16.32	852
	All Samples	850	155.40	5.47	789	3.90	812

Table 7.–Week of capture for Chinook salmon destined for the 4 major spawning sites of the Naknek River as determined by radio telemetry, 2004.

Week		Paul's Creek	King Salmon Creek	Big Creek	Naknek River
1	14–20 June	10	15	4	0
2	21–27 June	40	32	18	9
3	28 June–4 July	12	10	9	13
4	5–11 July	0	0	2	14
5	12–18 July	0	2	4	8
6	19–25 July	0	0	0	6
7	26–30 July	0	0	0	2
	Total:	62	59	37	52

Table 8.–Bank of orientation for Chinook salmon destined for the 4 major spawning sites of the Naknek River as determined by radio telemetry, 2004.

Bank	Pauls Creek		King Salmon Creek		Big Creek		Mainstem	
	Number	Proportion	Number	Proportion	Number	Proportion	Number	Proportion
Left	33	0.53	33	0.56	7	0.19	21	0.33
Right	17	0.27	15	0.25	23	0.62	23	0.37
Midchannel	12	0.19	11	0.19	7	0.19	19	0.30
Total:	62	1.00	59	1.00	37	1.00	63	1.00

Table 9.–Exploitation rate of harvested Chinook salmon from all user groups calculated with estimated abundance, Naknek River, 2003–2004.

Year	Harvest				Estimated abundance	Abundance and harvest	Exploitation Rate (%)
	Commercial	Subsistence	Sport	Total			
2003	564	1,221	2,412	4,197	23,231	27,428	15
2004	1,274	949	3,004	5,227	40,707	45,934	13

Source: Westing et al (2005); Jennings et al. (2006b, 2007)

Note: Estimated abundance includes an additional 13% expansion based on historic escapement into Pauls and King Salmon creeks (Sands et al. 2003).

FIGURES
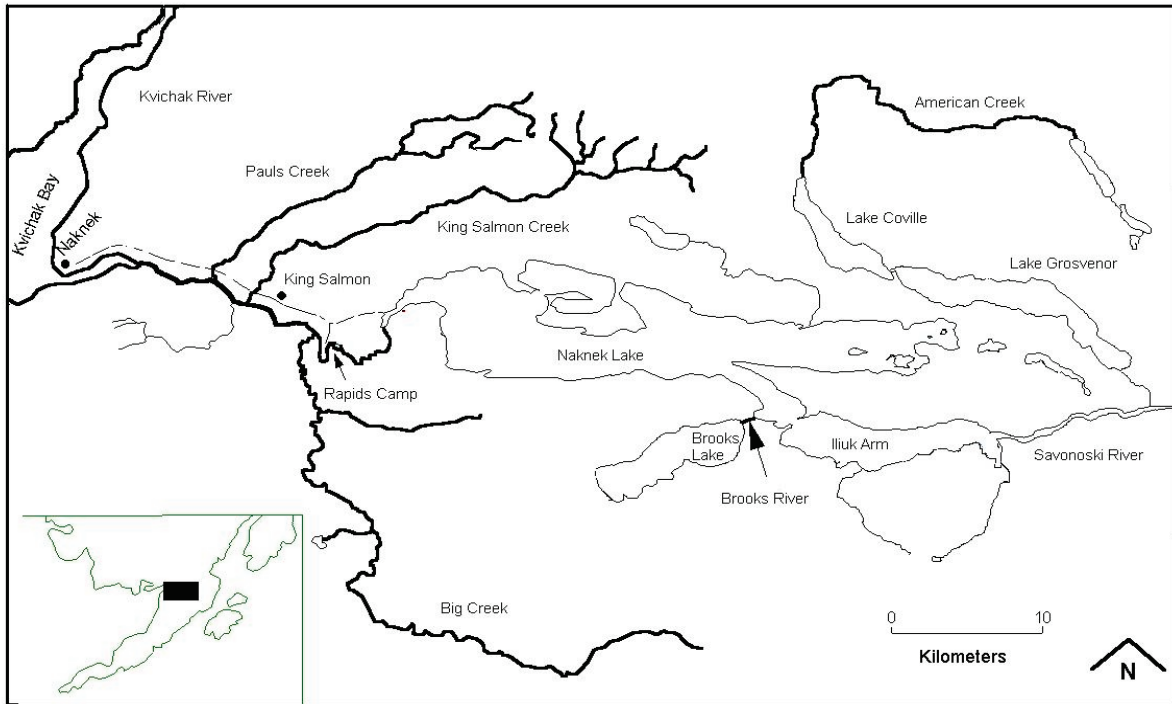
Figure 1.–Naknek River drainage.
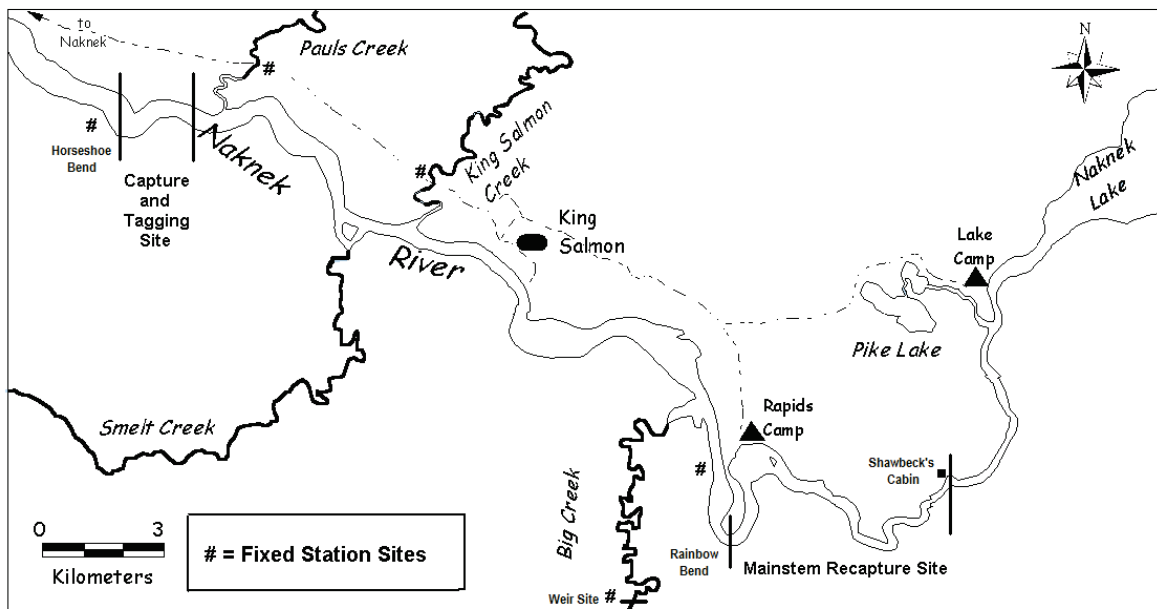
Figure 2.–Naknek River with marking and recapture sites, the locations of fixed stations, and the Big Creek weir site.

Figure 3.–Length frequency distribution of Chinook salmon captured during the marking event on the Naknek River, 2003.

Figure 4.–Age frequency distribution of Chinook salmon captured during the marking event on the Naknek River, 2003.

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Figure 5.–Length frequency distribution of Chinook salmon sampled at the Big Creek weir, 2003.
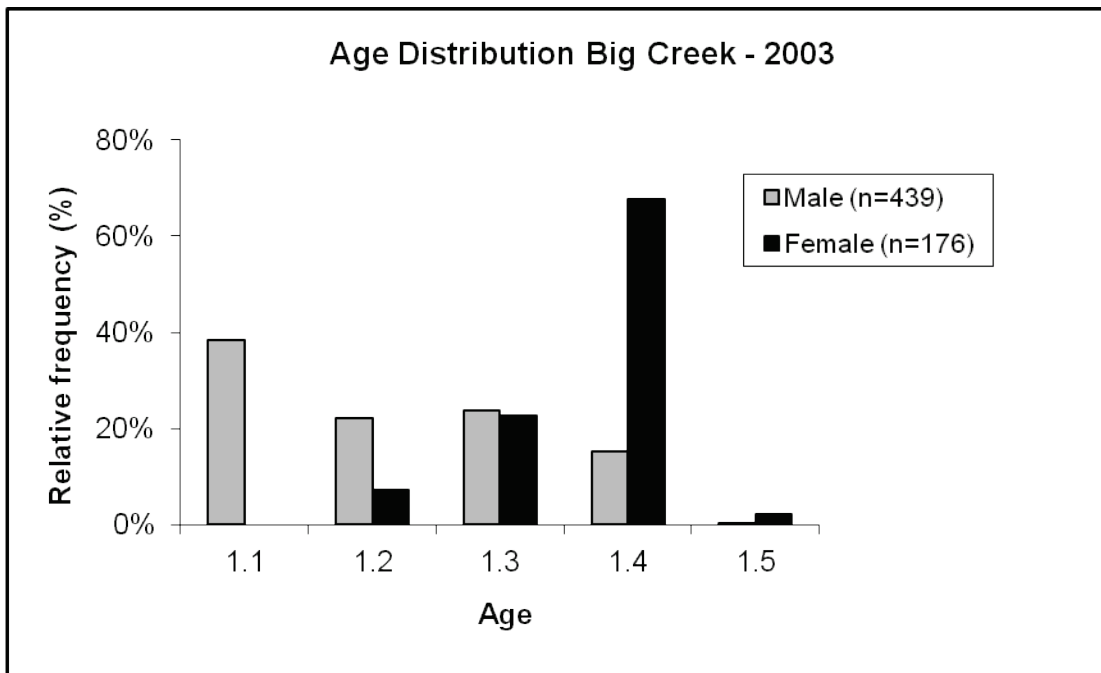
Figure 6.–Age frequency distribution of Chinook salmon sampled at the Big Creek weir, 2003.

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Figure 7.–Length frequency distribution of Chinook salmon captured during the recapture event on the mainstem of the Naknek River, 2003.

Figure 8.–Age frequency distribution of Chinook salmon sampled during the recapture event on the mainstem of the Naknek River, 2003.
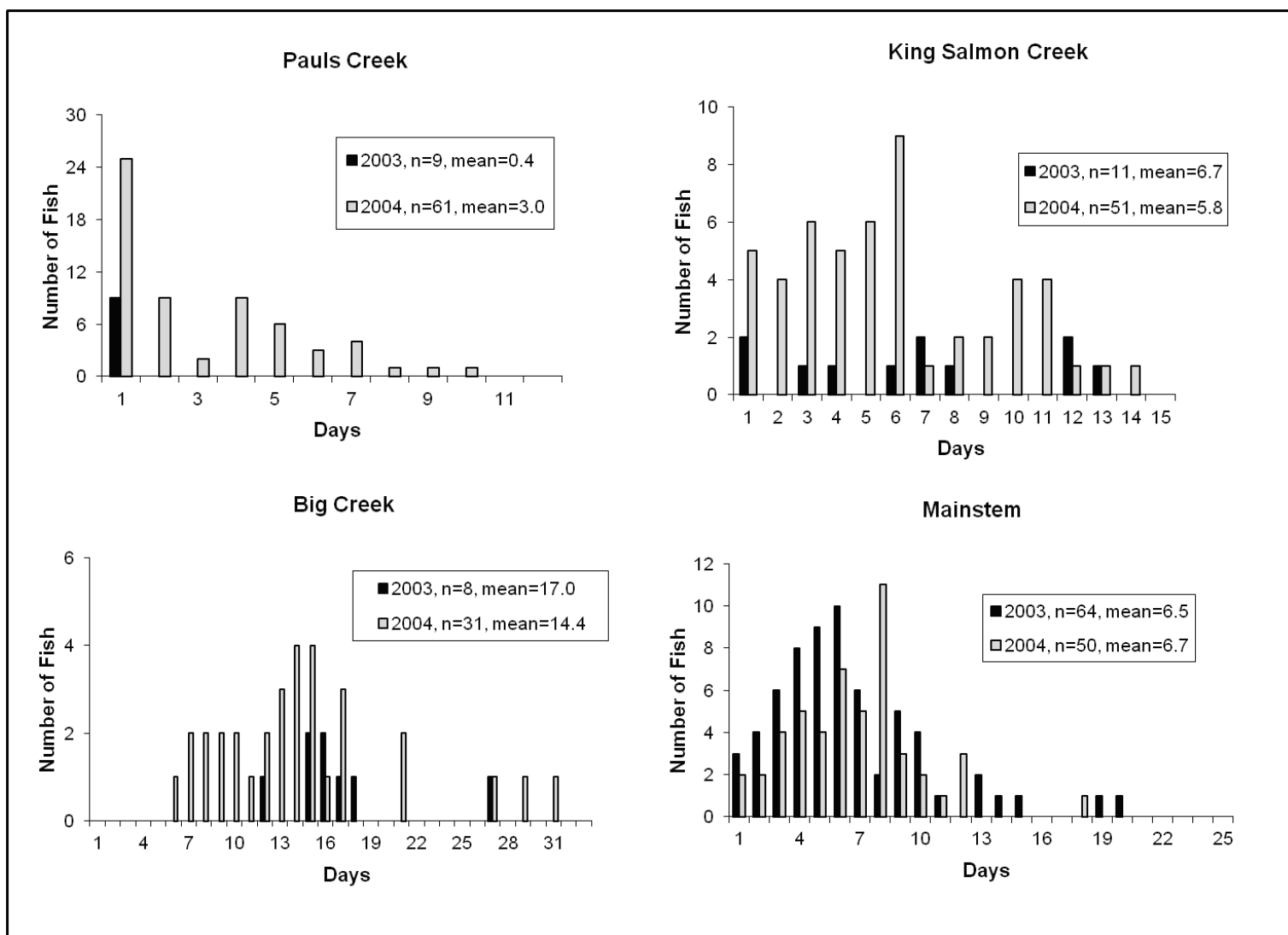
Figure 9.–Number of days for a radiotagged Chinook salmon to reach fixed stations at each of the 4 major spawning sites of the Naknek River, 2003–2004.
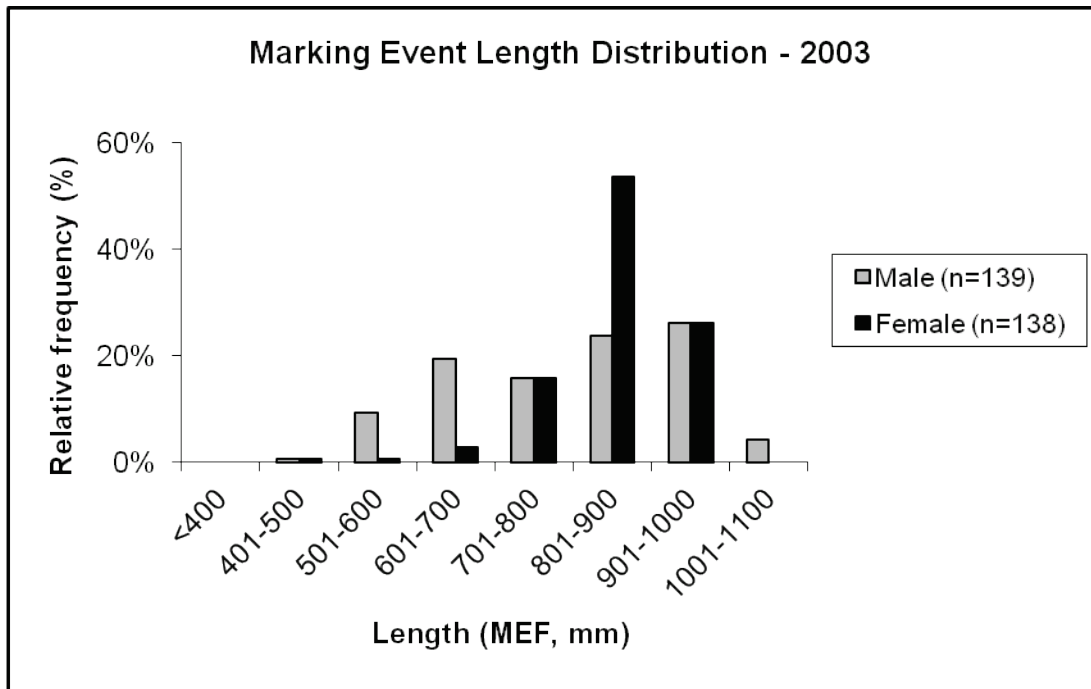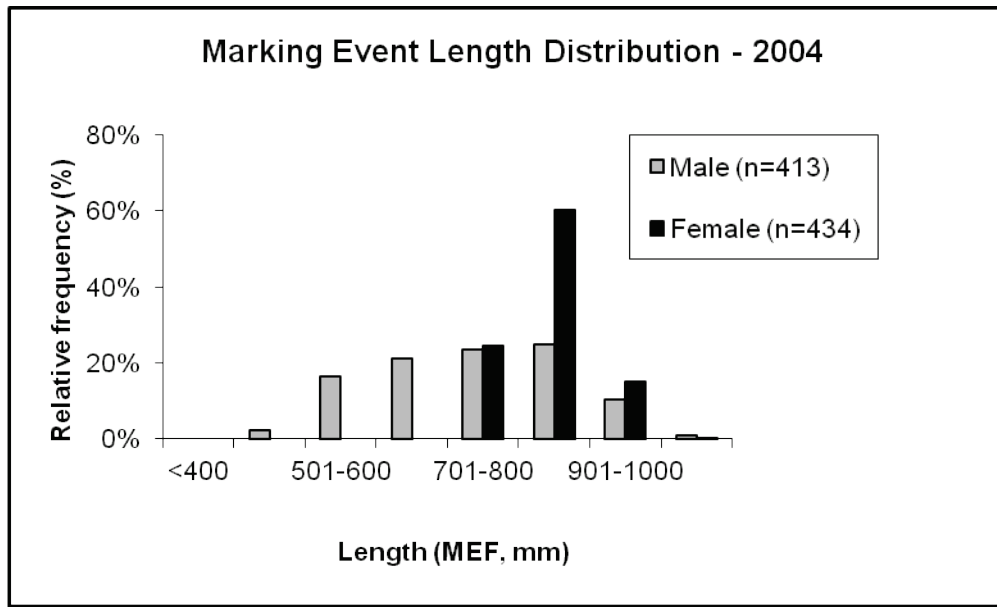
Figure 10.–Length frequency distribution of Chinook salmon captured during the marking event on the Naknek River, 2004.
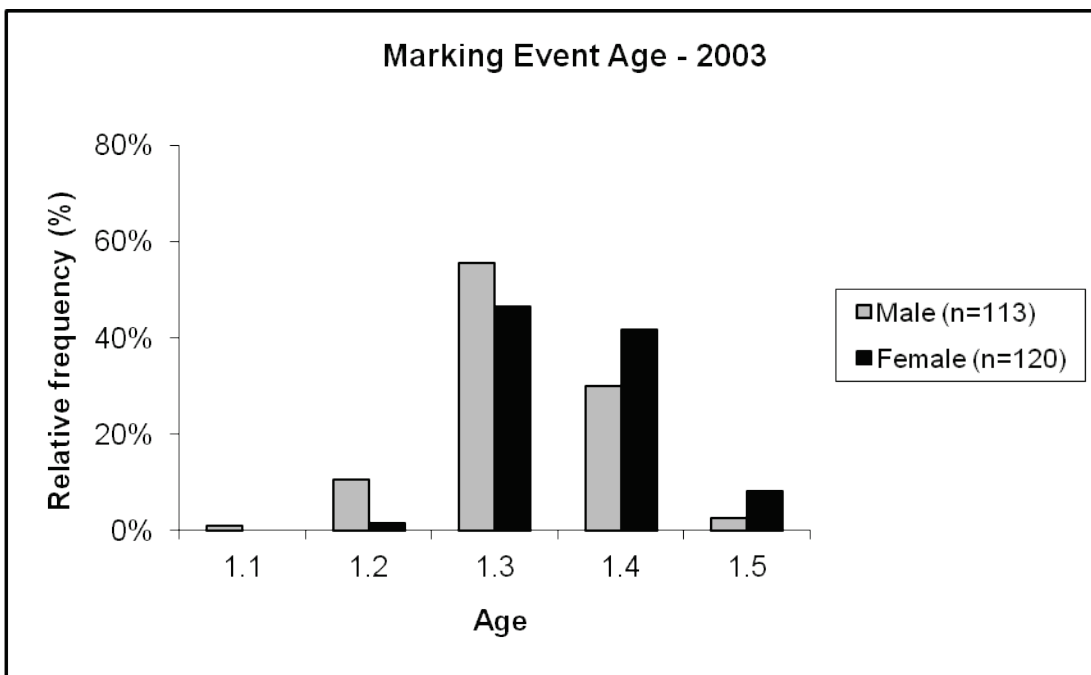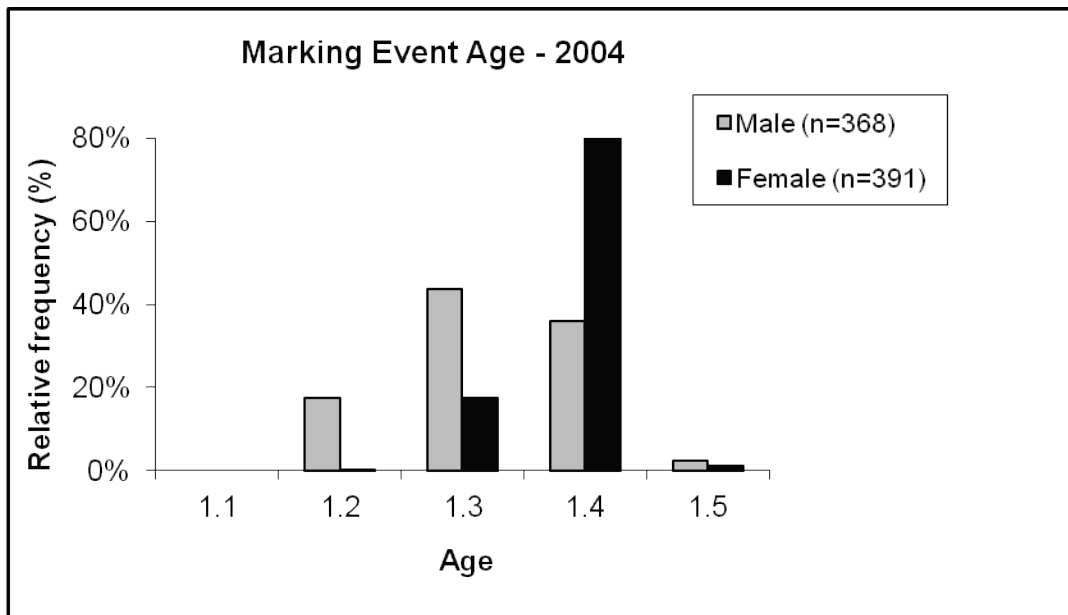

Figure 11.–Age frequency distribution of Chinook salmon captured during the marking event on the Naknek River, 2004.
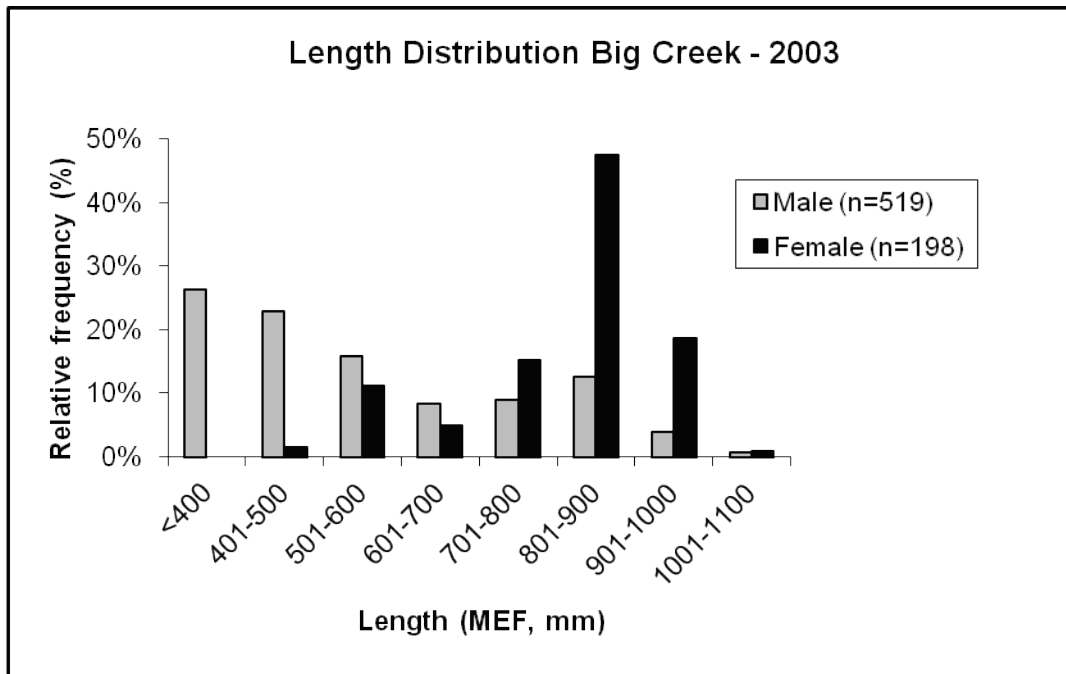
39
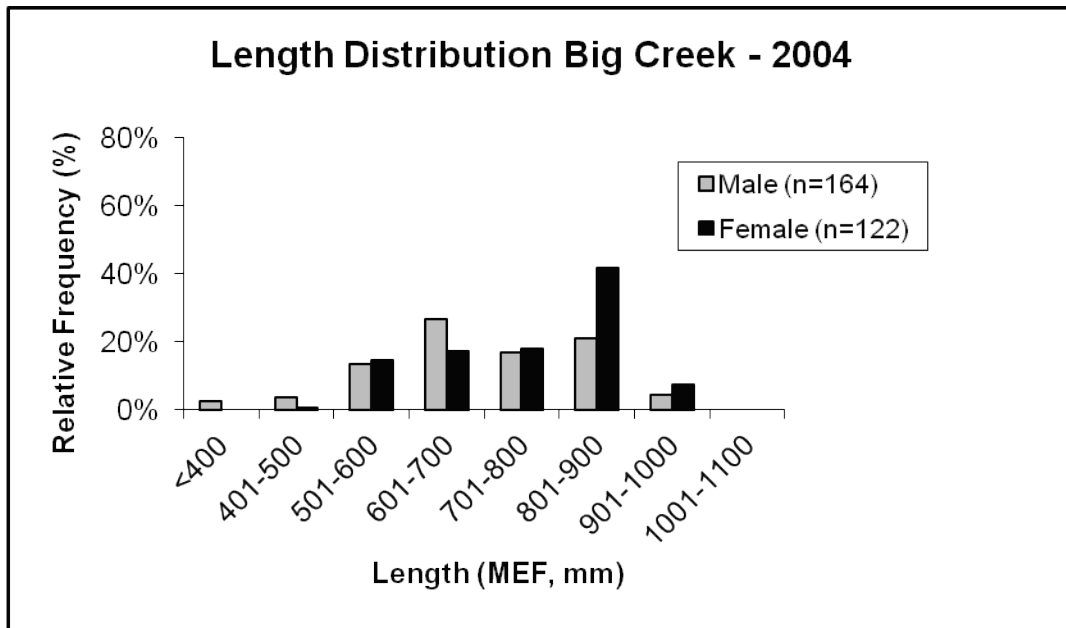
Figure 12.–Length frequency distribution of Chinook salmon sampled at the Big Creek weir, 2004.
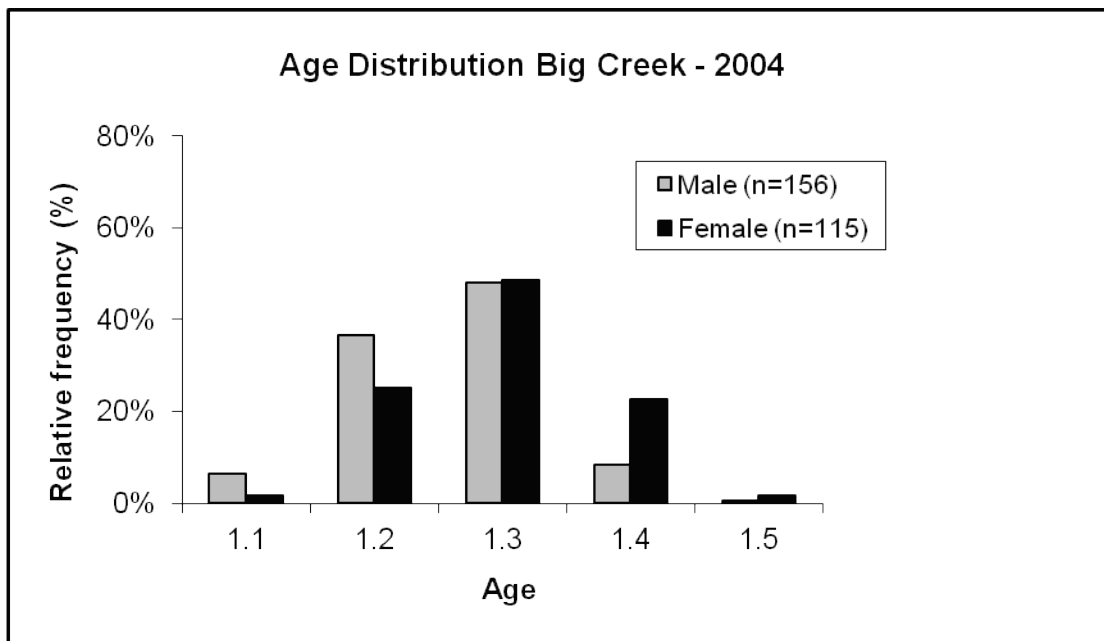
Figure 13.–Age frequency distribution of Chinook salmon sampled at the Big Creek weir, 2004.

Figure 14.–Length frequency distribution of Chinook salmon captured during the recapture event on the mainstem of the Naknek River, 2004.

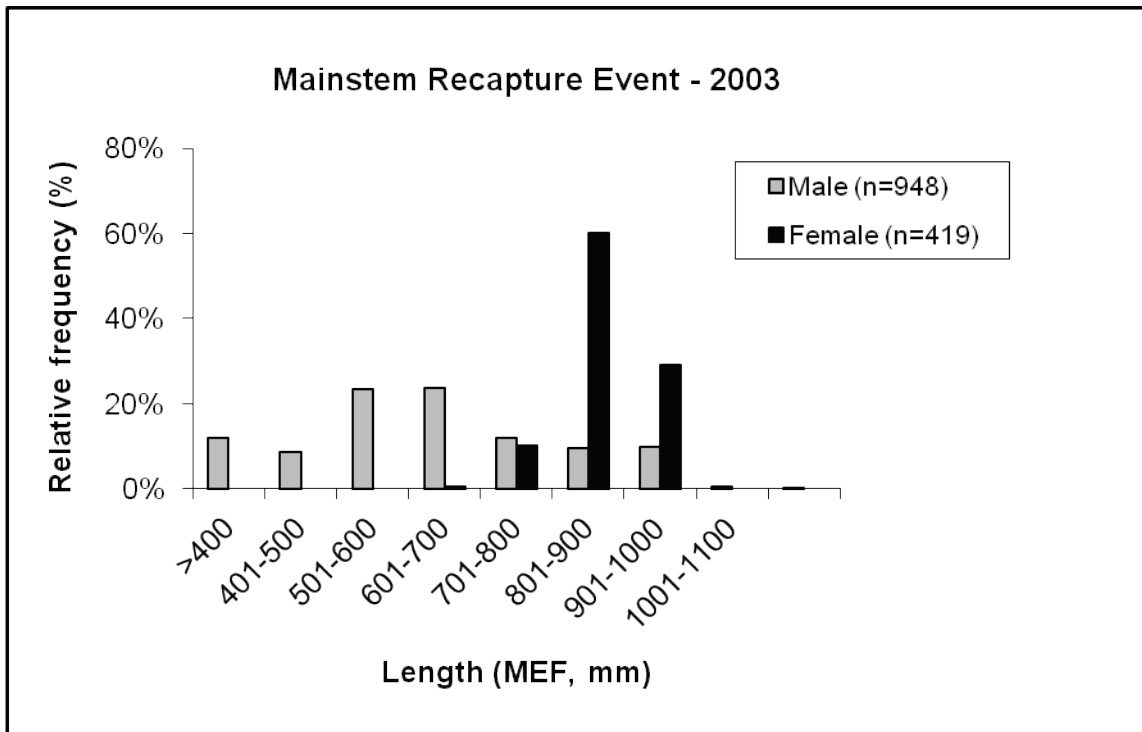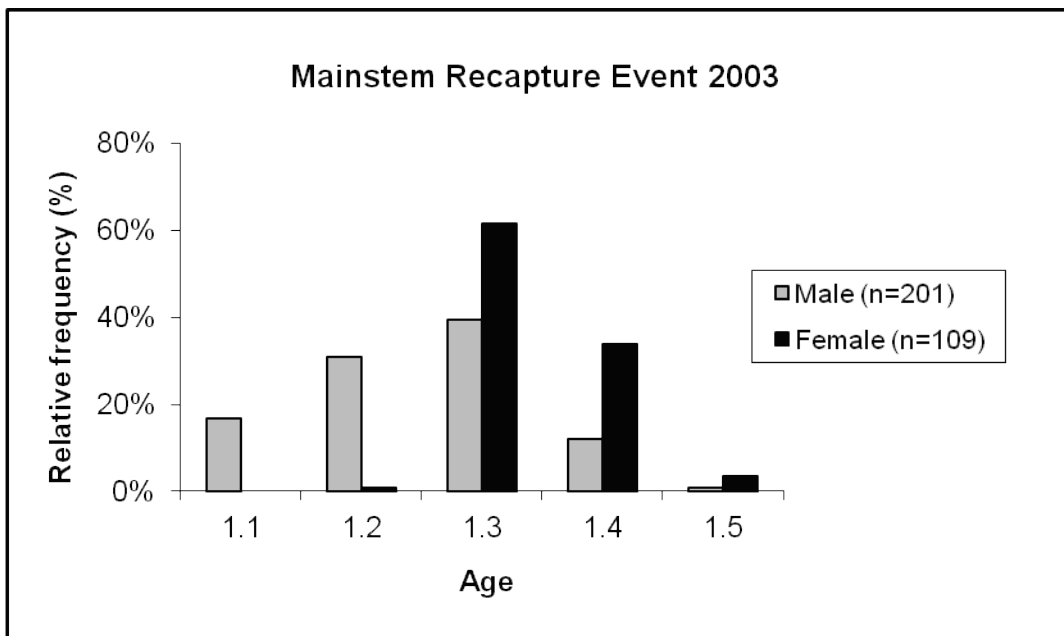Figure 15.–Age frequency distribution of Chinook salmon sampled during the recapture event on the mainstem of the Naknek River, 2004.
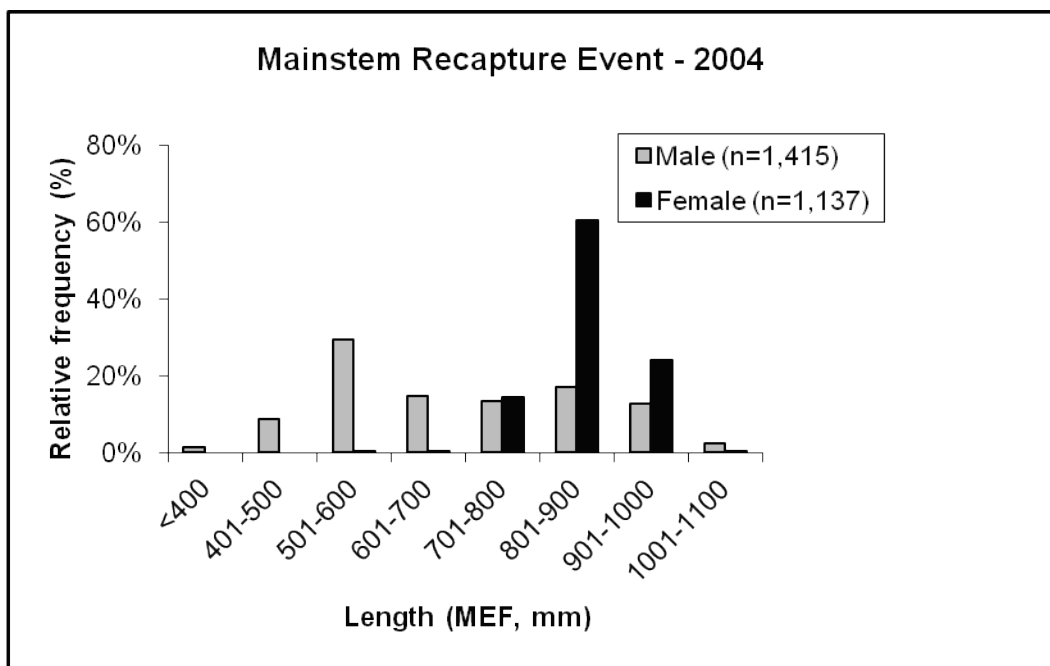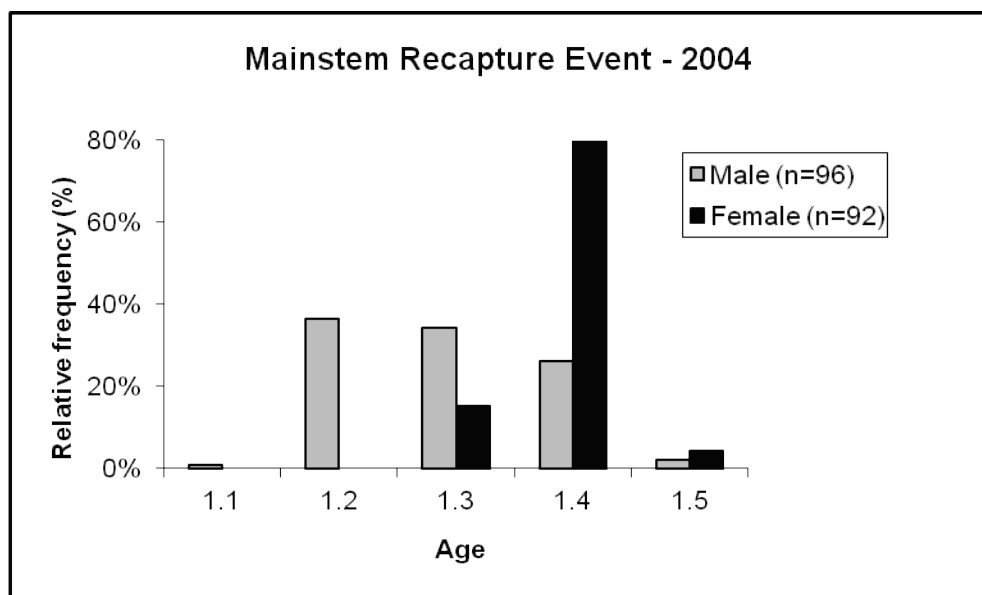
APPENDIX A: METHODOLOGIES FOR DETECTING AND ALLEVIATING BIAS DUE TO GEAR SELECTIVITY

Appendix A1.-Methodologies for detecting and alleviating bias due to gear selectivity.

Size selective sampling: The Kolmogorov-Smirnov (K-S) 2-sample test (Conover 1980) was used to detect significant evidence that size selective sampling occurred during the first or second sampling events of the mark–recapture experiment. The first sampling event (all fish captured for marking) was evaluated for bias by comparing the length frequency distribution of all fish inspected for marks during the second sampling event (C) with that of marked fish recaptured during the second event (R). The second sampling event (all fish captured to inspect for marks) was evaluated for bias by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R). In both cases, a null hypothesis of no difference was used. A third test, comparing M and C, was used to evaluate the results of the first two tests if sample sizes were small. Sample sizes were considered small if they were less than 30 for R and less than 100 for M or C.

Sex selective sampling: A contingency table analysis (chi-square test) was used to detect significant evidence that sex selective sampling occurred during the first or second sampling events of the mark–recapture experiment. The counts of observed males to females were compared between M and R, C and R, and M and C as described above. Comparison tests used a null hypothesis that the probability of sampling a particular gender of fish is independent of the sample. When the proportions by gender were *estimated* for a sample (usually C), rather than *observed* for a sample, contingency table analysis was not appropriate and the proportions of females (or males) were compared between samples using a 2-sample test (e.g., Student's *t*-test).

M versus. R	C versus. R	M versus. C
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o
There is no size/sex selectivity detected during either sampling event.		
Case II:		
Reject H_o	Fail to reject H_o	Reject H_o
There is no size/sex selectivity detected during the first event but there is during the second event sampling.		
Case III:		
Fail to reject H_o	Reject H_o	Reject H_o
There is no size/sex selectivity detected during the second event but there is during the first event sampling.		
Case IV:		
Reject H_o	Reject H_o	Reject H_o
There is size/sex selectivity detected during both the first and second sampling events.		
Evaluation Required:		
Fail to reject H_o	Fail to reject H_o	Reject H_o

Sample sizes and powers of tests must be considered:

A. If sample sizes for M versus R and C versus R tests are not small and sample sizes for M versus C are very large, the test of M versus C is likely detecting small differences which are unlikely to result in bias during estimation. *Case I* is appropriate.

B. Given a test comparing M versus R, if sample sizes are small, and the *P*-value is not large (~0.20 or less), and given a test comparing C versus R, if sample sizes are not small and/or the *P*-value is fairly large (~0.30 or more), the rejection of the null hypothesis in the M versus C test was likely the result of size/sex selectivity during the second event, which the M versus R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

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C. Given a test comparing C versus R, if sample sizes are small, and the *P*-value is not large (~0.20 or less), and given a test comparing M versus R, if sample sizes are not small and/or the *P*-value is fairly large (~0.30 or more), the rejection of the null hypothesis in the M versus C test was likely the result of size/sex selectivity during the first event, which the C versus R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. Given tests comparing C versus R and M versus R, if sample sizes are both small, and both *P*-values are not large (~0.20 or less), the rejection of the null hypothesis in the M versus C test may be the result of size/sex selectivity during both events, which the C versus R and M versus R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

Scenarios for calculating abundance estimates:

Case I. Abundance is calculated via a Petersen-type model (equation 1) and the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II. Abundance is calculated using a Petersen-type model and using the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M versus R test) within strata. Composition parameters are then estimated within strata, and abundance for each stratum is estimated using a Petersen-type model. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III. Abundance is calculated using a Petersen-type model and using the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C versus R test) within strata. Composition parameters are then estimated within strata, and abundance for each stratum is estimated using a Petersen-type model. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, an overall composition parameter (p_k) is estimated by combining within stratum composition estimates using

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ , and} \tag{1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \left(\sum_{i=1}^{j} \hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + \left(\hat{p}_{ik} - \hat{p}_k \right)^2 \hat{V}[\hat{N}_i] \right) \tag{2}$$

where

j	=	the number of sex/size strata,
$\hat{p}_{ik}$	=	the estimated proportion of fish that were age or size *k* among fish in stratum *i*,,
$\hat{N}_i$	=	the estimated abundance in stratum *i*,
$\hat{N}_\Sigma$	=	sum of the $\hat{N}_i$ across strata.

APPENDIX B: DAILY FISHING EFFORT, CATCH, AND NUMBERS OF TAGGED CHINOOK SALMON FOR MARKING EVENTS, 2003–2004

Appendix B1.–Daily fishing effort, catch, number of radiotagged fish and CPUE for the Naknek River Chinook salmon marking event, 2003.

Date	Fishing effort (hr)	Captured	Cumulative	Radio tagged	Cumulative	CPUE
1-Jun	4.1	0	0	0	0	0
2-Jun	4.4	0	0	0	0	0
3-Jun	4.8	0	0	0	0	0
4-Jun	0.5	0	0	0	0	0
5-Jun	3.8	0	0	0	0	0
6-Jun	2.9	0	0	0	0	0
7-Jun	4.1	0	0	0	0	0
8-Jun	3.5	0	0	0	0	0
9-Jun	4.4	0	0	0	0	0
10-Jun	4.9	0	0	0	0	0
11-Jun	4.2	0	0	0	0	0
12-Jun	3.8	0	0	0	0	0
13-Jun	2.2	0	0	0	0	0
14-Jun	3.4	3	3	1	1	0.87
15-Jun	4.3	0	3	0	1	0
16-Jun	4.8	0	3	0	1	0
17-Jun	4.0	0	3	0	1	0
18-Jun	3.9	0	3	0	1	0
19-Jun	4.1	0	3	0	1	0
20-Jun	3.6	1	4	1	2	0.28
21-Jun	4.7	1	5	1	3	0.21
22-Jun	3.5	2	7	2	5	0.57
23-Jun	1.6	2	9	2	7	1.28
24-Jun	2.9	5	14	4	11	1.74
25-Jun	2.7	3	17	2	13	1.10
26-Jun	1.4	11	28	10	23	7.86
27-Jun	1.3	0	28	0	23	0
28-Jun	3.1	1	29	0	23	0.32
29-Jun	3.6	8	37	6	29	2.21
30-Jun	3.3	4	41	4	33	1.22
1-Jul	3.0	6	47	6	39	2.03
2-Jul	1.8	2	49	2	41	1.10
3-Jul	2.3	3	52	3	44	1.29
4-Jul	3.4	4	56	3	47	1.18
5-Jul	3.3	2	58	2	49	0.61
6-Jul	4.5	5	63	5	54	1.12
7-Jul	4.8	2	65	2	56	0.41
8-Jul	3.9	7	72	6	62	1.79
9-Jul	4.1	5	77	5	67	1.22
10-Jul	3.3	17	94	17	84	5.15
11-Jul	2.4	10	104	9	93	4.17
12-Jul	2.6	19	123	17	110	7.43
13-Jul	2.6	14	137	12	122	5.47

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Date	Fishing effort (hr)	Captured	Cumulative	Radio tagged	Cumulative	CPUE
14-Jul	2.9	9	146	8	130	3.07
15-Jul	3.4	8	154	7	137	2.39
16-Jul	3.6	8	162	6	143	2.22
17-Jul	2.9	5	167	3	146	1.75
18-Jul	3.2	6	173	5	151	1.89
19-Jul	3.1	6	179	6	157	1.94
20-Jul	2.0	11	190	10	167	5.62
21-Jul	3.8	3	193	3	170	0.80
22-Jul	3.6	10	203	10	180	2.79
23-Jul	3.1	15	218	14	194	4.86
24-Jul	3.2	6	224	5	199	1.86
25-Jul	3.3	9	233	7	206	2.72
26-Jul	3.2	11	244	9	215	3.39
27-Jul	2.5	13	257	10	225	5.13
28-Jul	3.4	7	264	6	231	2.08
29-Jul	3.5	5	269	5	236	1.43
30-Jul	4.1	4	273	4	240	0.98
31-Jul	3.6	4	277	3	243	1.13
					Mean CPUE:	1.36

Appendix B2.–Daily fishing effort, catch, number of radiotagged fish, number of externally-tagged fish, and CPUE for the Naknek River Chinook salmon marking event, 2004.

Date	Fishing effort (hrs)	Captured	Cumulative	Radio tagged	Cumulative	External tag only	Cumulative	CPUE
14-Jun	3.6	3	3	3	3	0	0	0.84
15-Jun	3.7	4	7	4	7	0	0	1.08
16-Jun	3.0	16	23	13	20	0	0	5.33
17-Jun	4.3	4	27	3	23	0	0	0.93
18-Jun	3.6	6	33	6	29	0	0	1.69
19-Jun	3.0	13	46	11	40	0	0	4.29
20-Jun	3.2	2	48	2	42	0	0	0.63
21-Jun	6.0	18	66	17	59	0	0	3.01
22-Jun	4.2	18	84	16	75	0	0	4.29
23-Jun	4.0	18	102	17	92	0	0	4.52
24-Jun	5.1	28	130	20	112	0	0	5.47
25-Jun	5.0	40	170	28	140	0	0	7.95
26-Jun	2.4	41	211	20	160	0	0	17.32
27-Jun	0.8	9	220	5	165	0	0	12.00
28-Jun	1.1	19	239	16	181	0	0	16.76
29-Jun	4.3	38	277	12	193	11	11	8.87
30-Jun	4.2	53	330	17	210	16	27	12.77
1-Jul	3.4	32	362	7	217	15	42	9.55
2-Jul	2.6	14	376	3	220	4	46	5.45
3-Jul	4.0	27	403	4	224	15	61	6.75
4-Jul	5.5	21	424	4	228	16	77	3.85
5-Jul	5.4	23	447	4	232	10	87	4.27
6-Jul	1.9	23	470	4	236	12	99	12.21
7-Jul	2.7	26	496	4	240	10	109	9.69
8-Jul	2.8	26	522	4	244	9	118	9.29
9-Jul	1.5	18	540	4	248	6	124	12.13
10-Jul	3.3	19	559	4	252	5	129	5.82
11-Jul	3.3	12	571	4	256	1	130	3.60
12-Jul	4.2	12	583	5	261	2	132	2.89
13-Jul	3.0	12	595	4	265	1	133	4.00
14-Jul	2.4	22	617	5	270	8	141	9.30
15-Jul	2.3	22	639	5	275	8	149	9.50
16-Jul	3.1	17	656	5	280	6	155	5.43
17-Jul	3.2	17	673	4	284	7	162	5.37
18-Jul	2.5	20	693	3	287	4	166	7.95
19-Jul	2.9	22	715	2	289	8	174	7.72
20-Jul	2.9	20	735	1	290	9	183	6.86
21-Jul	3.0	13	748	4	294	3	186	4.33
22-Jul	3.3	12	760	4	298	3	189	3.69
23-Jul	2.6	15	775	3	301	5	194	5.70
24-Jul	3.1	11	786	3	304	3	197	3.57
25-Jul	4.0	5	791	2	306	1	198	1.26
26-Jul	2.8	16	807	2	308	2	200	5.82

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Date	Fishing Effort (hrs)	Captured	Cumulative	Radio tagged	Cumulative	External tag only	Cumulative	CPUE
27-Jul	3.7	11	818	2	310	0	200	2.96
28-Jul	3.1	12	830	1	311	10	210	3.83
29-Jul	2.4	4	834	0	311	3	213	1.70
30-Jul	3.0	16	850	1	312	5	218	5.27
31-Jul	Did Not Sample		850		312		218	
							Mean CPUE	5.49